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FINAL REPORT

July 31, 1956

ADVANCED RECONNAISSANCE SYSTEM

COMPONENT RELIABILITY STUDY

RADIO CORPORATION OF AMERICA

DEFENSE ELECTRONIC PRODUCTS
CAMDEN, NEW JERSEY

and

RCA LABORATORIES
PRINCETON, NEW JERSEY

Contract AF 33(616)3641

DOWNGRADED AT 12 YEAR

WD-57-0000

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FINAL REPORT

(U) ADVANCED RECONNAISSANCE SYSTEM COMPONENT RELIABILITY STUDY

DOWNGRADED AT 3 YEAR INTERVALS;
DECLASSIFIED AFTER 12 YEARS.
DOD DIR 5200.10

Prepared for:

WRIGHT AIR DEVELOPMENT CENTER
Dayton, Ohio
Contract No. AF33(616)3641
Exhibit No. 56-8

Prepared by:

RADIO CORPORATION OF AMERICA
RCA Laboratories
Princeton, New Jersey
Defense Electronic Products
Camden, New Jersey

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CHAPTER I

INTRODUCTION

A. PURPOSE OF PROGRAM

This report satisfies the requirements specified in R & D Exhibit 56-8, dated 9 February 1956. This exhibit covers the work necessary to provide the Advanced Reconnaissance System with a comprehensive reliability review to establish system design goals.

The exhibit states that "electronic component parts selected for this system, in conjunction with application criteria, must have a level of reliability such that the probability of 10,000 hours successful system operation is great. Probabilities of successful operation for 17, 250, 1000, and 3500 hours must also be determined." In this work, the application of the component quite frequently is such that the number of hours of successful operation necessary for a successful performance of the ARS mission is considerably below 10,000 hours. For example, certain transmitting equipment in the vehicle will have to operate for only 800 hours out of the entire year of orbital life.

In several instances, there was only fragmentary information available. In these cases, then -- the nuclear source and the orbital altitude and sensing control equipment -- a valid discussion of reliability was impossible without more detailed data.

The exhibit requires an operational plan; such a plan appears in Chapter X, "Conclusions and Recommendations.

B. LIMITATIONS

In meeting the requirements of this contract, it was necessary to make value judgements concerning several products currently available. The Radio Corporation of America wishes to make it clear that these judgements apply only to the proposed use of these components in the Advanced Reconnaissance System. Further, it should be noted that it was not always possible to test all the products currently available to meet a specific need. Hence, the list of satisfactory components is not to be considered necessarily complete.

C. GENERAL VEHICLE REQUIREMENTS

The purpose of the Advanced Reconnaissance System is to obtain pictorial and ferret intelligence from enemy territory. It will consist of artificial earth satellite containing a reconnaissance package and associated communications equipment, power supplies, and scientific instrumentation. The equipment in this package must be capable of satisfactory operation without maintenance. The only adjustment possible will be by remote control through the communications link. The equipment must be capable of withstanding the conditions of ascent and then operating under the considerably different conditions to be found in orbit. A description of the two sets of conditions, based on the best information available to the contractor, is contained in a later portion of this introduction.

It has been pointed out[1] that the vehicle with a reconnaissance package is not expected to spring into being full blown but rather that a series of systems of increasing reconnaissance usefulness will evolve. The very early systems will have as their primary purpose the gathering of information about the orbital environment and testing the

1. ARS Development Plan.

operation of various component parts and subsystems under orbital conditions. There will be a series of systems from which reconnaissance information will be obtained but whose primary function will be the testing of reconnaissance techniques and the use of the ARS data. Finally there will be a class of vehicles whose primary purpose is reconnaissance.

TABLE I

Life Requirements of Satellite Systems

Test Vehicle	.999	3 hours	3000 hours
	.96	120 hours	
	.85	500 hours	
Early Reconnaissance	.99	500 hours	50,000 hours
	.95	2500 hours	
	.82	10,000 hours	
Final Reconnaissance	.99	2500 hours	250,000 hours
	.96	10,000 hours	

To get a rough idea of the life requirements of these systems it is convenient to refer to a set of probabilities of the entire system lasting a fixed time. To conform with the current practice an "equivalent mean life" is also listed. This mean life is computed on the assumption that the system failures are specified by a negative exponential probability distribution.[1] For example the first entry in the table for an early test vehicle lists as a requirement that the system have a probability of .999 of lasting 3 hours, this is equivalent to the requirement that the system have a mean life of 3000 hours. All of the probabilities listed here are conditional on the vehicle getting on orbit with the equipment in working condition. A word is in order about the choice of the time

1. The formula for computing mean life is, under this restriction obtained from $P_s = \exp(-t_0/T)$ where $P_s(t_0)$ is the probability that the item will last a time t_0 and T is the mean life. A further remark of some use is to note that for fixed T $P_s(kt_0) = (P_s(t_0))^k$.

and probability pairs. The shortest useful time was picked and assessment was made of the acceptable chance of failure of attaining that time. This then determines the mean life. Additional times of interest are also listed with the probability implied by the shortest useful time. For the early system a shortest useful time of two revolutions is considered desirable to get an estimate of environment.

When examining the table note that a slight change of emphasis will make a considerable change in the requirements. For example, suppose it were considered important that the 500 hour time was a breakeven point (i.e. the probability of surviving 500 hours is .5) the mean life would then be 722 hours and the probability of survival for 3 hours would be .994.[1]

It should also be remembered in examining this table that these requirements are failure and mean life requirements for the total mechanism. For illustration suppose the only items contributing to early failure in the test vehicle were the transponder, clock, telemetering equipment and television camera; that the four subsystems are independent; and that a failure in any one would abort the mission. With these assumptions each subsystem must then have a mean life of 12,000 hours and the associated probability of one subsystem lasting 3 hours is .99975. This is an unduly pessimistic way of looking at the problem and in later sections it will be noted that introduction of redundancy, relaxation of the independence restriction, a more realistic statement about the relative importance of subsystems and the use of cycled operation can all improve the situation to an extent. In this introduction the examples and expositions have all been restricted to an exponential failure model in a later section the applicability of various other models will be discussed at some length.

1. This points up strongly a characteristic of the assumption of exponential distribution of failures namely, to get relatively small improvement in short life characteristics it is necessary to increase the long term life greatly.

The systems requirements of ARS are severe, the environment in which the system operates is unusual, the cost of getting a vehicle to orbit is high, and the information to be gained from the use of the vehicle is of tremendous importance. These conditions make it mandatory that careful consideration be given to those aspects of component use and development which will help insure satisfactory system performance. The key to obtaining this performance lies in painstaking care in designing and building ARS as a system. This implies that extreme care must be given to the selection, fabrication, and application of component parts to meet the system requirements. Discussion of policies and techniques which RCA believes to be sound for exercising this care form an important portion of this report. Many of the techniques such as the components application review, derating policies, tailored testing, and reliability prediction have had their effectiveness demonstrated in regular use at RCA. Other methods such as the inspection on the vendors production line, high percentage destructive sampling, computer simulation of parts performance, etc. have been successfully used by others.

In addition to the discussion of techniques this report gives a preliminary summary of information of the performance of high population part such as resistors, capacitors, and tubes; test information on batteries; information on the state of the art on such special parts as vidicons and magnetrons, magnetic tape, an indication of cost of development of some of the necessary special items; an indication of the magnitude and cost of necessary test equipment; and a series of recommendations for further study.

The basic information on ARS has come from reports produced at RCA under Contract AF33(616)-3104.

CHAPTER II

THE ARS PAYLOAD AND ITS ENVIRONMENT

ARS vehicles will progress from the models used early in the program to gather basic environmental data, through an interim group of vehicles which will be capable of performing some useful reconnaissance, to the final vehicles which will utilize the reconnaissance equipment and techniques evolved during tests of the two earlier groups. Each of these groups will carry a somewhat different payload; hence our discussion of the effects of environment begins with a description of the types of payload that will be subjected to the environment.

The environmental factors affecting the components separate very conveniently into those which are effective during ascent and those effective during orbit. The environment during ascent is of short duration and is similar in all other respects to that of the ICBM. The environment on orbit is that environment in which the equipment must operate for a long time. The features of this environment which can have considerable effect on equipment operation are air density, meteoric bombardment, cosmic radiation, effects of solar heating, and ultraviolet irradiation.

A. THE ARS PAYLOAD

1. Early Test Vehicles

The early ARS vehicles will be used primarily for gathering environmental data and testing the effect of the environment on certain of the basic ARS components. This vehicle will have its electronic equipment powered by batteries which will have no means of being recharged. The electronic equipment (exclusive of special scientific apparatus) will consist of:

1) Transponder with several communication channels
2) Clock
3) Telemetering transmitter
4) Vidicon television camera

The most important piece of equipment in the early vehicle is the transponder. The mere tracking of the vehicle will give information about the earth's gravitational fields and drag acting on the vehicle. This information is basic to the design of the satellite system and hence it was decided that for maximum reliability two transponders with independent power supplies would be sent aloft. If the transponder works even though the other equipment fails the early mission will be successful. The transponder will permit communications with the vehicle and tracking to establish the orbit, air-induced drag, and by inference, the air density. Scientific data will be transmitted from the orbiting vehicle over the nine or more channels available in each of the transponders. Since two transponders with independent power supplies will be used, at least 18 channels of communication will be available between vehicle and ground. The transponder will operate at C band. The most likely transponder for the early vehicles appears to be a modification of APN/DPN Bowlegs developed for the Signal Corps.

The electromechanical clock envisioned for use in the early vehicles will be primarily a programming device. However, there are excellent possibilities for the design of an electronic clock utilizing transistors and with extremely low power requirements.

The telemetering transmitter in the early vehicle will be used for the transmission of information during the ascent phase of the vehicle. In the early vehicle the direct transmission television images will be sent over the telemeter transmitter. No decision has been made as to the telemetering equipment to be used.

The vidicon camera will be similar to one used in a current RCA project[1] in which the camera is used in a narrow band system. The assumptions used in the design of the ARS camera are:

1) Use of a lens with focal length of 4 inches
2) Exposure time of 0.01 second, based on image imobilization and the sensitivity of the vidicon
3) A maximum video frequency of 75 kc to permit use of the telemetering transmitter

The picture from such a camera is sufficient to show gross geographic phenomena such as shore lines and would demonstrate the feasibility of transmission of pictures from a satellite.

The operation of any of the equipment is completely dependent on the operation of batteries and hence, the operation, packaging, and connecting of the batteries is crucial to the success of the first vehicle. For this reason considerable effort has been placed on determining some of the operating characteristics of batteries.

2. Interim Reconnaissance Vehicles

a. Power Supplies. Power supplies for the interim vehicles will be either non-rechargeable batteries or early versions of a solar power supply, probably one utilizing solar batteries. Both types of power supply will restrict the power available to the equipment. The use of non-rechargeable batteries will also cause a serious restriction on the vehicle life.

[1] Study of Army Television Problems, Signal Corps Contract DA36-039-sc-70122.

b. Television Payload. Two types of systems have been considered. The first utilizes photographic film which is processed in the vehicle and transmitted to the ground using a flying spot scanning technique for the generation of a video signal. The mechanically vibrating scanner appears to be the most promising for the operation. The second system utilizes a very simple television-magnetic tape system. In this system the input information is maintained in parallel channel form throughout the entire pickup process. The system utilizes a separate television pickup tube (a half-inch vidicon) for each frame track on the ground and a separate magnetic tape storage channel for each vidicon. Such a multitube assembly has been made possible by the development of transistor deflection circuits and the half-inch vidicon. The total weight of the assembly would be under 10 pounds and the power requirements under 4 watts. This system would require approximately 2,000 feet of tape which would permit a tape transport mechanism using 10 watts of driving power and weighing 6 pounds. Both of the systems are designed for a ground resolution of approximately 100 feet.

c. Ferret Reconnaissance Payload. The earlier ferret equipment will be used for obtaining reconnaissance information and for testing techniques to be used in later more sophisticated systems. Two systems are under consideration for the interim system - a scanning superheterodyne and a crystal video with preamplifier. Both systems would use five antennas directed downward to cover the frequency range from 700 to 12,000 mc. The average power requirement is to be under 75 watts. Using antenna beamwidths believed to be reasonable, a point on the ground will be in the antenna beam for approximately 10 seconds.

A superheterodyne can be made to scan a frequency range of about one octave several times during this period without using unreasonable scan rates or bandwidth. (See figure 2-1) Thus is offered the possibility of securing very good discrimination between radars on the basis of frequency ($\pm$ 1 percent or better), at a reasonable cost in weight and power consumption. This ability to separate signals will help to a large degree to alleviate the problems posed by the very large number of radars in the antenna beam.

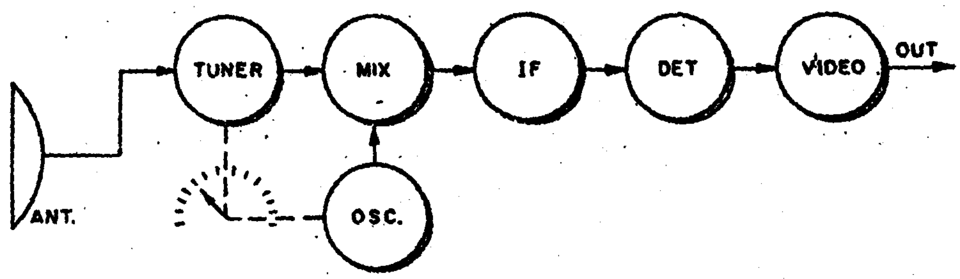

Figure 2-1
Simple Superheterodyne Ferret System

Each antenna would be connected to its own superheterodyne receiver having a tuner and oscillator which require tracking over a frequency range of 1.8:1. The outputs of the tuner and oscillator are mixed and fed to the i-f amplifier. This is followed by the detector and video amplifier and finally the signal is recorded on magnetic tape for storage. This system may prove more desirable than the crystal video type because the required sensitivity could be obtained without the use of traveling wave tubes.

Figure 2-2 shows a simplified arrangement of one section of this system. In this system each antenna would be followed by a broad-band traveling wave amplifier. This in turn would feed one or more filters followed by a video amplifier. The filters would be arranged to divide the frequency spectrum with their outputs gated successively for storage on magnetic tape. The frequency spectrum might be covered continuously by a series of bands with emphasis placed on greater accuracy in bands having a greater interest factor. To provide sufficient gain and desired beamwidth each antenna would require a paraboloidal reflector. During the ascent phase of the vehicle flight, these structures would require being housed within the vehicle. Erection outside would take place after the vehicle is in orbit. A total of five receiving systems similar to figure 2-2 would be required to cover a band of frequencies from 700 to 12,000 mc.

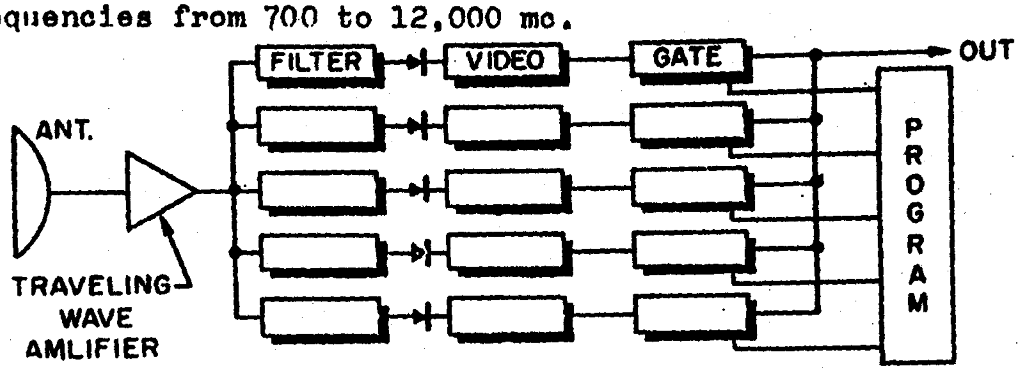

Figure 2-2
Crystal Video with Preamplifier

The recorder is a multichannel magnetic tape unit. It is used for storing the intercept data for transmission to the ground. Each of the channels might be gated "on" once every 2 seconds providing at least five measurements on a given signal per pass of the vehicle. For chosen bands of high signal interest the accuracy of the frequency measurement could be ± 5 percent. Location accuracy is expected to be within the area covered by the antenna, or when expressed in linear dimensions, between the limits of 67 and 38 miles, depending on the frequency being received.

d. Communications. The television transmitter for the interim vehicle would include a crystal-controlled oscillator and multipliers to approximately 400 mc. The output amplifier would be a grid-modulated 2C39B, which can readily produce the desired output power running at about half normal dissipation.

An output filter would produce vestigial sideband transmission to decrease interference with other services. The receiver would also be crystal controlled and would operate at a frequency differing from the transmitter by a few percent. This would permit simultaneous transmission and reception on a single antenna by means of a relatively simple filter. The antenna would be such as to give a cone-shaped beam radiating from the vehicle and covering the earth to the horizon in all directions.

The programming unit will be the same electromechanical clock and timing mechanism described for the test vehicles. The clock will be set every few passes from the ground station. It will turn the radio receiver, television camera, ferret receivers off and on. It will also be used to turn off and on various pieces of measuring equipment.

The telemetering unit will include multiplexing means to permit measuring the outputs of a number of transducers and of various voltages throughout the airborne system. While several well-designed telemetering systems are now available, some modification of the chosen design would be necessary to improve reliability. Telemetering data can be sent back over the television transmitter and over the channels available in the transponder.

The transponder will be a modified version of those used in the test vehicles.

3. Final Reconnaissance Vehicle

a. Power Supplies. For power requirements not greater than 250 watts, orbital average solar power supplies appear to be adequate. The most likely supply will be a solar battery supply with the possible alternative development of a solar heated thermocouple supply.

For power requirements greater than 250 watts orbital average, a nuclear power supply appears to be necessary. The two types currently under consideration are:

1) Reactor heat source and boiler, prime mover, generator, the so-called conventional supply
2) Reactor heat source and thermocouples.

Both systems are considered capable of delivering 1 kilowatt average power. Both systems present severe radiation problems since a reactor of the proposed type will emit gamma rays at 2000 roentgens/hour at a distance of 15 feet.

b. Television Payload. RCA offers two processes which are strong contenders for selection as the advanced subsystem. The first of these, the electrostatic-television process, is an outgrowth of this Corporation's work on photoconductive picture tubes. It offers the advantages of simplicity and the reliability that results therefrom. In this process an image of the earth is deposited in the form of a pattern of electrostatic charges on tape of an insulating material. This tape is stored with the electrostatic image on its surface. When the vehicle comes within radio range of the ground station, the tape surface is scanned by an electron beam to produce a video signal. The tape is then wiped clear of all charges and is available for reuse.

In simplest form, the tape is almost identical to the photo surface used in the RCA vidicon tube, with which we have had extensive experience. All available data on this type of surface indicate that a high sensitivity and a long storage time are conflicting requirements. However, recent work on a new type of surface has shown that it is possible to separate the parameters which affect sensitivity from those which affect storage time. While it is too early to state with certainty, the data at hand lead us to believe that sensitivities on the order of those of the production image orthicon, storage times equal to several orbital periods, and definition comparable to that of photographic film can be achieved. This work was done on RCA funds, and a more detailed explanation of the process cannot be given until our proprietary rights have been adequately protected.

To achieve the maximum definition and information rate of which the tape is capable, the ultimate video bandwidth has been set at about 8 mc. Tests have shown that the resultant pictures will be many times sharper than the picture presented by the best home receiver.

The image handling capabilities of this process can be used in a large number of ways to meet the wishes of the Air Force. Two examples follow. If the optics are so chosen that a 110-foot object can be detected, then each ground picture will cover an 8-by-10 mile area, there will be 36 such pictures in a strip stretched across the direction of the vehicle's travel, and the length of this strip will be 374 miles. The outside edge of the end picture will be seen at an angle of 32° from the vertical. These strips will be repeated to form a swath 374 miles wide across the unfriendly area. If, on the other hand, the optics were chosen to permit detecting 25-foot objects, then each ground picture will cover an 1.9-by-2.5-mile area, there will be 10 such pictures in each strip for a total strip length of 23 miles, and the outside edge of the end picture will be seen at an angle of 2.2°

from the vertical. Again the 23-mile swath would cross the unfriendly territory.

This electrostatic-television process offers several advantages over other systems. Unlike the television-magnetic process, the electrostatic-television process does not store a video signal. Instead, it stores an image of the ground in which there is an area-for-area relation to the surface of the earth. The length of the tape required is therefore essentially the same as the length of film that would be required to photograph the earth. A considerable equipment simplification results. Unlike the photographic television system, no expendable supplies are used. The life of the equipment is limited therefore only by the slow deterioration of bearings, vacuum tubes, etc.

The second process, the television-magnetic process, has been under study and development at RCA since it was proposed by this Company while working as a sub-contractor to the Rand Corporation[1], and the exploratory work has progressed to the point where there is no doubt that it can be made to work. In this process the ground is examined by a television camera using an image orthicon tube, the video signals are stored on a magnetic tape during the time necessary for the vehicle to pass from unfriendly territory to within radio range of the ground station, and the tape is then played back and its signal sent to the ground by radio. The tape is then wiped clear of all signals and is available for reuse.

Two camera tubes are used, both to provide duplication of equipment and to permit the most advantageous cycle of operation. By optical means these tubes take a series of pictures in a line across the direction of the vehicle's flight. In practice, one tube is exposed for a fraction of

[1] Rand Corporation subcontract 52-63, June 1952.

of a second to the optical image, then this tube is scanned to generate the video signal. While the first tube is being scanned, the second tube is exposed and the optics of the first tube are changed so as t o present a different picture area for its next exposure. This action is continued as the vehicle moves forward so that a mosaic of photographed areas is formed.

As in the electrostatic process, a video bandwidth of 8 mc has been chosen, and again the picture is expected to be many times sharper than the picture of the best home receiver. This wide-band signal is then broken down into several narrower frequency bands, and these are recorded side by side on separate tracks on the magnetic tape. Control signals are recorded at the same time, and these are used to control the movement of the tape during playback.

Although the television-magnetic process in inherently the more complicated of the two, this Corporation has under way a number of developments which may so greatly extend the usefulness of any process based on the image orthicon that its advantages will support its complexity. It is now possible to build a commercial image orthicon with greater spacing between the target and its mesh. This tube is more critical of the applied level of light than is the standard tube, but it is about 10 times as sensitive and permits observation in the light of a full moon. There has also been built at the David Sarnoff Research Center a tube with two image sections. This tube is farther from commercial production, but the development models have had sufficient sensitivity to permit observation by starlight. It is obvious that these tubes would increase the number of observational passes possible with each vehicle; in addition, the best available information shows that cloud cover is less at night, so the effectiveness of night-time passes would be greater than that of day passes. Use of these tubes therefore offers a significant increase in the amount of useful data that can be derived from each vehicle.

c. Ferret Payload. After type I has been flown for about a year, a power supply of higher capacity (250 watts) is expected to become available. At that time the type II ferret should be ready for flight tests. The second type ferret will be an extension of the first type. It will be capable of the same functions but will perform these functions with greater accuracy and will in addition measure pulse width and PRF. The frequency range will be extended [redacted] if the need is demonstrated and if techniques allow. Digital techniques will be used where an advantage is gained thereby.

In addition a start should be made on the problem of extending the low end of the frequency ranges. This problem is difficult. It will not be practical to use the same scheme as for type I at [redacted] It will be necessary either to relax the location accuracy required or to use a different scheme involving interpolation. It is believed that one section of such a scheme should be included in the type II ferret.

After type II has been flight tested for about a year a still higher capacity power supply (1 kilowatt) is scheduled to become available. The type III ferret should be ready for flight test at that time. The design of the type III ferret will be carried out during the flight tests on type I and the experience and data obtained during the tests should be very helpful. It will also be possible to make minor changes in the type III equipment if the need is indicated by tests on the type II equipment.

The third ferret system will be based on the first and second systems. However, it will have an extended frequency range covering, [redacted] The frequency, location, PRF and pulse width of radars will be measured. Consideration will also be given to covering CW reception. This third type will be different from the first two types in that considerable effort will be expended in providing a more accurate indication of location.

d. Communications. There is a possibility of changing to a steerable antenna with an attendent change in television transmitters. The transmitter would operate at a frequency of 7500 mc. A possible microwave tube for this application would be an improved 7500 mc version of the RCA A-1061 frequency-modulated magnetron. Satisfactory television pictures could be obtained at 1600 miles with a vehicle transmitter output of from 5 to 10 watts. A major difficulty with such a system is positioning the vehicle antenna.

No major change from the interim system is considered for the other parts of the vehicle communications.

B. ARS ENVIRONMENT

1. Ascent Phase

a. Atmospheric Conditions. The vehicle starts out under normal surface ambient air conditions. The total time for ascent to orbital height is on the order of 30 to 35 minutes, during which time the atmospheric pressure is reduced to the order of 10^{-8} to 10^{-10} mm of Hg. The atmospheric temperature at first drops to a low of approximately 200° K, then from approximately 100 kilometers altitude proceeds to rise to from 1000° to 1500° K. However, the ambient temperature has relatively little meaning in regard to the internal temperature of the vehicle, because of the fact that during ascent skin friction raises the skin temperature to hundreds of degrees above ambient, and at the orbital altitude of 500 kilometers the air is too rarefied to conduct any appreciable amount of heat to or from the vehicle. During ascent it is estimated that the nose cone of the vehicle may reach temperatures corresponding to approximately 1000° K but that the skin around the payload compartment will not be hotter than approximately 600° K.

b. Total Vector Accelerations. While at rest on the ground all of the payload is of course subject to the ordinary 1g steady gravitational acceleration. On launching, the rocket motors provide a steadily increasing acceleration which may reach a peak of from 7 to 10g; superimposed on this steady acceleration there will be severe vibrational accelerations. The exact nature of the vibrations is not known but it has been stated by WDD that the vibrational amplitude may be as high as 1 inch peak-to-peak, have peak magnitudes as high as 10g, and have components, subject to these limits, up to 2000 cycles per second. After the booster and the main vehicle motors are shut off there is a coast phase during which the vehicle experiences no net acceleration, but this coast phase is followed by a short vernier acceleration of a relatively low value. The ascent accelerations either in the booster or vernier phase may contain transverse as well as longitudinal components; these may become particularly severe in the booster phase.

c. Cosmic Radiation. The primary cosmic ray intensity increases with increasing altitude, but the secondary cosmic rays arising from the constituents of the atmosphere cause the total counting rates to reach a maximum at an altitude of approximately 60,000 feet. It is not likely that these secondaries arising from the atmosphere will cause any unusual radiation effects in excess of those arising at orbital altitudes from the effects of the primaries striking the vehicle structure.

2. Orbital Phase

a. Atmospheric Conditions. At vehicle altitudes it is estimated that the atmospheric pressure will be in the order of from 10^{-8} to 10^{-10} mm Hg, the actual value being uncertain by a factor of 100 to 1. The temperature is estimated to be between 1000 and 1500° K. The main constituents of the air at these altitudes are expected to be O, N, N_2, and possibly He; it is expected that all of the oxygen will be dissociated but the extent of the dissociation of the nitrogen is less well known.

The main detrimental effect of the ambient atmosphere is of course the drag which it applies to the ARS vehicle, but it is possible that other deleterious effects may arise from physical or chemical interaction of the air atoms and molecules on the vehicle skin or lens and window materials. The quantity of molecules present is very low, in the order of 10^6 to 10^8 per cc, but the relative velocity of the molecules to the vehicle may give them sufficient kinetic energy to disrupt lattice bonds in the metal of the skin, and thus change the thermal radiation properties of the skin in the course of time. However, these effects are expected to be small.

The state of ionization of the atmosphere at vehicle altitudes is unknown; there are theories which predict virtually no ionization, and others which predict almost complete ionization. The electron density may be as high as 10^5 per cc, but this does not represent a sufficient density to pose any troublesome atmospheric conductivity effects.

b. Total Vector Acceleration. At the center of gravity of the vehicle there are no vector accelerations during orbiting conditions except the extremely slight deceleration due to drag. Above and below the center of gravity there are very slight accelerations, but for all practical purposes the entire vehicle may be considered to be in a gravity-free condition.

c. Cosmic Radiation. Primary cosmic ray particles consisting of protons and α particles of several Bev energy are expected to strike the vehicle at the rate of approximately 1 per cm^2 per second. It is expected that these will produce negligible effects on any electronic component. Secondary radiations arising from the vehicle structure may contain γ rays, neutrons, and various fission fragments, but these are also expected not to be harmful, although this assumption is considerably more uncertain than that made with respect to the damage from the primary cosmic rays.

d. Vehicle Skin Temperatures. The predicted vehicle skin temperatures depend heavily on the assumed values of the skin absorptivity α and emissivity ϵ. Present estimates for a titanium skin lead to the prediction that skin temperatures over various parts of the vehicle will vary from 400° K to 170° K, although the average skin temperature is only approximately -10° C. Preliminary estimates on the temperature that would be assumed by a centrally located payload box indicate that it would remain at approximately 25° C if it only exchanged heat with the vehicle skin by means of radiation.

e. Meteorite Bombardment. Estimates of material structural damage due to meteorite impact indicate that this problem will probably not be too severe; one estimate made by North American Aviation Company predicts an average of one destructive impact every 6 months.

The magnitude of the erosion problem due to cosmic dust is much more uncertain. There are some indications from rocket flight that a rather severe sand blasting or erosion effect may take place. Certain other estimates based on such indirect factors as the silicon content of the ocean beds lead to predictions of little real trouble from cosmic dust erosion. This is one of many points which can only be settled by flight tests in early satellite vehicles.

f. Solar Radiation. The received solar radiation at 500 km will contain much more energy in the ultra violet and X-ray region than that received at sea level or normal airplane flight altitudes. This shorter wave content will probably not affect the vehicle skin or structure but it may discolor or craze plastic surfaces such as might be used for containing solar batteries.

CHAPTER III

PERFORMANCE OF HIGH-POPULATION COMPONENTS

A. GENERAL CONSIDERATIONS

Taken individually, the indicated environmental extremes present few if any insurmountable problems within the present state of the component and materials art. The temperature range of $-37^{\circ}C$ to $125^{\circ}C$ is one with which the components industry has had a great deal of experience on military equipments. At $125^{\circ}C$ judicious selection will be necessary to make available the complete variety of parts suitable for the numerous circuit applications. This upper temperature limit will also place a premium on maintenance of reliability.

The reduced air pressure, in the presence of ionization will present serious voltage flashover problems, particularly during the transition from ground pressure through the critical pressure point.[1] In general, flashover can be controlled by maintaining adequate spacing between electrodes, by proper shape of the electrodes, by potting or pressurizing. The effects of reduced pressure on hermetic seals is not considered serious in most component categories. Available seals have adequately performed up to altitudes of 70,000 feet even under the added stresses of high temperature. The increased pressure contributed by altitudes above 70,000 feet is not sufficient to cause concern.

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1. Mankin, Arthur H., "Corona Suppression Methods", Electrical Manufacturing, June 1951, p.125.

However, where O-ring or elastometer seals (as opposed to a true hermetic seal such as Kovar Glass Seal) are used, particularly where volatile substances are enclosed, will require special consideration and possibly development effort. Because of the wide spectrum of vibration frequencies, the anticipated shock, and the high acceleration contributed by rocket powered flight, heavy components may require special moorings. All components, even the smallest, will have to be supported by suitable brackets unless encapsulation is used. The effects of ultraviolet or cosmic radiation were not considered because of lack of information. It is not expected that this will create any unanticipated hazards. However, some further investigation should be conducted in this area. Due to the limited time of this study, no consideration has been given to the effects of nuclear radiation on components and the conclusions drawn here may not apply to a satellite using a nuclear power source. Humidity is not a problem during flight. It may be a problem during storage of some of the component categories, but this can be overcome by proper packaging and storage under controlled environments and careful control of the inventory. All factors considered, a satellite life span of 10,000 hours does not appear to be excessive.

The advantages of potting or encapsulation to minimize flahsover, dampen the effects of shock and vibration and provide a heat transfer medium should be seriously considered. Likewise, pressurization will solve many of the flashover problems and provide a medium for heat exchange between dissipative components and the other masses within the vehicle.

An overall evaluation of the ARS environment shows that the components and materials problems exist primarily in two main areas. First, available test data present no information on the ability of components to withstand combined stresses of voltage and/or current in the changing atmosphere of increasing temperature and rarification, in the presence of ionization and nuclear radiation, under the mechanical forces of the high acceleration of rocket powered flight, and when subjected to severe shock and vibration. Yet, this is the environment that components will undergo during launching. The second problem is the maintenance of a high order of reliability for each component and to maintain this reliability throughout the process of assembly of the equipment. This reliability is dictated by the extremely high investment in time and funds in each vehicle.

Fortunately, there are mitigating factors. The violent launching cycle is of short duration. The greater part of the operating life span occurs under essentially ideal conditions. Orbiting except possibly for radiation (solar and cosmic) effects and chance collisions with "inter-planetory debris", will take place under the placid conditions of a moderate and stable temperature and equilibrium of mechanical forces. The profile of the launching stresses is not expected to change significantly from launching to launching. Exploratory telemetered launchings should make available the details of this profile. These data in turn will provide the basis for developing a reproducible, reasonably short, but highly protective proving-out procedure which can simulate actual launching stresses. The severity of the reliability problem is further reduced by the comparative simplicity (as compared with computers or the combined complexity of the communications, navigation and fire control gear of a bomber, for example), and low component population density of ARS. Add too, the probability that not all electronic equipments in ARS are critical to the survival of the vehicle or its ability to perform its primary mission.

B. DETAILED CONSIDERATIONS

1. Capacitors

The anticipated selection of circuits for the ARS program calls for a wide variety of capacitor types. The environmental extremes, particularly temperature and pressure impose many restrictions, but not to the point of exclusion of any essential types, (with the possible exception of radiation effects, which are not being explored herein). The environmental extremes will, however, aggravate the reliability problems (see paragraph D). In general, derating of voltage will effect a material increase in reliability.

a. Paper Capacitor. Subminiature paper capacitors, styles CP-05 through CP-11, characteristic K of MIL-C-25 as supplied by the Sprague Company and the Gudeman Company, are adequate for operation at 125°C for periods well in excess of 10,000 continuous hours. The compression glass header is preferred over the Kovar seal. Styles CP-04, CP-05, CP-08, and CP-09 will require suitable brackets to withstand the anticipated dynamic forces. Styles CP-10 and CP-11 are furnished with integral mounting means. However, CP-11 is to be avoided on account of the cantilever type of mounting which is not recommended for severe dynamic loading. The extended foil construction of styles CP-08 and CP-09 is preferred for low voltage application, (under five volts) and where self inductance (of tab construction) is not desirable circuitwise. Sufficient creepage distance between terminal and case must be maintained to preclude voltage flashover particularly during transition through the critical pressure point. The terminal and seal design of this capacitor is such that wide variation in creepage distance will be encountered under normal manufacturing techniques. This is particularly serious with Kovar glass headers. Accordingly, the larger diameter headers should be used especially for the higher voltage ratings. Where the creepage distance is marginal for the particular voltage rating all capacitors should be tested at the critical pressure point to cull out capacitors with inadequate spacing due to eccentricity in the rim seal solder or globs of solder in the eyelet seal. High temperature solder should be used for rim soldering of the header to preclude the possibility of the header moving under the influence of high temperature and dynamic loading.

b. Button Mica Capacitors. Both Erie Resistor Company and Sangamo Electric Company now make a glass seal button mica capacitor capable of withstanding the anticipated environmental extremes. However, the expected dynamic load will require special concern over the method of mounting the capacitor to the chassis. Solder alone should not be used for mechanical support.

c. Molded Mica Capacitor. Cornell Dubilier Electric Company has available a molded mica capacitor which will adequately withstand the temperature of 125°C. In addition, the Elmenco Dur Mica capacitor, the Corning Glass glass capacitor and the Vitremon, vitreous enamel capacitor are all suitable for operation at 125°C. These capacitors while normally supported by their wire leads should, for this application, be potted, pasted, or suitably bracketed to withstand the dynamic forces. In bracketing the vitreous enamel or the glass capacitor, due consideration should be given to the inherent fragility of the product. The voltage derating required in Specification MIL-C-11272 should be applied to all glass capacitors operating at 125°C.

d. Ceramic Capacitor. Ceramic capacitors, both temperature compensating and high K types, are not normally supplied for 125°C operation (see MIL-C-20 and MIL-C-11015A). However, the Erie Resistor Company as well as other vendors are now making ceramic capacitors suitably housed and impregnated with high melting point wax capable of operation at 125°C. These capacitors should be potted, pasted, or bracketed to withstand dynamic loading. This class of products too, is very fragile and caution should be exercised in the method of bracketing.

e. Electrolytic Capacitors. The aluminum electrolytic capacitor is not suitable for use in ARS. However, tantalum electrolytic capacitors as supplied by the General Electric Company (foil construction) and the P. R. Mallory (slug construction) specially designed for 125°C operation may be used. Double sealed units are preferred in view of the possibility of loss of electrolyte by evaporation under the combined effects of temperature and reduced pressure.

f. Variable Air Dielectric Capacitors. In applying variable air dielectric capacitors it is essential that adequate spacing be maintained between capacitor plates to withstand peak voltage stress, particularly during the transition through the critical pressure point. In addition, unless shaft locking devices are provided it can be expected that the capacity will change under the rigors of the dynamic load.

g. Teflon Capacitors. Except for possible radiation effects, the teflon capacitor, because of its extremely high insulation resistance is eminently suited for time constant, energy storage, and integration circuits. This film is capable of suitable operation at temperatures well above 125°C. This capacitor should be preferably packaged in glass or ceramic tubes with metal end seals. The more common metal can, with glass end seal, will degrade the excellent characteristics of this capacitor.

2. Coaxial Cables

a. General Purpose Coaxial Cable. Except for the possible effects of radiation, teflon is the only dielectric material now available which can supply the excellent electrical characteristics desired, is practical for use in the manufacturing of coaxial cable, and can withstand temperatures up to 125°C. The jacketing material now available is monochlorotrifluoroethylene, teflon, or glass braid. Small cables having this desired construction are:

CABLE TYPE	NOM. (INCH) OD OVER JACKET	NON. (OHMS) IMPEDANCE	JACKETING MATERIAL JACKETING MATERIAL
RG-178 1/4	0.075	50	CTFE+ or Teflon
(Amphenol)	0.100	50	CTFE+ or Teflon
K-256 (FT&R)	0.135	50	CTFE+
RG-141/4	0.190	50	Glass braid
RG-142/4	0.205	50	Glass braid
RG-179/4	0.100	75	CTFE+ or Teflon
K-257 (FT&R)	0.135	70	CTFE+
RG-140/4	0.230	75	Glass braid
RG-180/4	0.145	95	CTFE+ or Teflon

If larger cables are required the selection should be made from specification MIL-C-17B.

\+ CTFE is monochlorotrifluoroethylene

b. Pulse Cable. There are no standard pulse cables available that will meet the 125°C temperature requirement. If short lengths are required it may be feasible to use shielded silicone-insulated high voltage wire covered by a glass braid. There is an experimental design, identified as No. 1230 by the Signal Corps, which can be used at 125°C. However, the cable outer diameter is 2.1 inches.

c. Delay Lines. There are none available that will meet the 125°C temperature requirement. It is suggested that the system use lumped-constant networks to accomplish the same task.

d. Installation Note. Extreme caution must be used to prevent failures due to vibration and shock. The cable should be fixed to the chassis at sufficient intervals to minimize cable whipping. This of particular importance at the ends of the cable. The cable immediately adjacent to the connector termination should be clamped to the chassis or to an extended support mounted to the chassis.

3. Coaxial Connectors

The 125°C temperature requirement limits the choice of the non-metallic material used in the connectors. Teflon, except possibly for its degradation under radiation, should be used as the insert material in all locations requiring optimum electrical characteristics. When the non-metallic material serves as a gasket or seal, but only mechanically (as opposed to electrically), then silicone should be used.

a. Screw-Type Connectors. Screw-type connectors should be locked together by a method such as solder or wire-locking.

b. Bayonet-Type Connectors. Bayonet-type connectors should be used only if the screw-type is not available or if a cramped location for coupling prevents a screw-type connection. The coupled connectors should be locked together by either solder or wire-locking.

c. Quick-Connect Snap-On Connectors. Quick-connect snap-on connectors should be used only if the cramped location for coupling prevents use of the screw or bayonet-types. The coupled connectors should be locked together either by solder or wire-locking.

d. Plug-in Connectors. Plug-in connectors should only be used for rack and panel coupling.

4. Motors

The major problem involved in the use of motors in ARS is maintaining adequate lubrication and satisfactory brush life. The lubrication problem may be solved by sealing the motor and using a silicone grease. However, the use of a silicone grease necessitates derating the mechanical loading on the bearings. Other known lubricants will not withstand the high temperature and reduced pressure. It may be possible to eliminate the brush problem by the use of brushless motors (assuming a-c power is available). If this is not possible, sealing the motor may solve the problem, but testing will be required to determine the necessary atmospheric conditions (in terms of moisture content) inside the motor for adequate life.

The insulation problem can be solved adequately by the use of class H or class B insulation.

5. Power and Data Type Connectors

The variety of available connectors which meet the environmental requirements of this project necessitates a review of the specific applications to facilitate selection of the optimum connector. In general, two types of connectors, the cable connector and the rack and panel connector are discussed below to provide a picture of connectors in general. High temperature solder must be used to hold the wires to the contacts and to rim seal the hermetically sealed connectors.

a. Cable Connectors. Class E, class K, and hermetically sealed cable connectors meet the specified environmental requirements for use in the interconnection of circuits between packaged units.

(1) Class E Cable Connectors. This class of connectors conforms to Specification MIL-C-5015B. It is recommended where the connector will be subjected to heavy condensation and rapid changes in temperature or pressure and/or where the connector is subjected to very high vibratory conditions. For class E connectors those with silicone insert material, as manufactured by Cannon Electric, are recommended. This class of connectors is not recommended for pressure tight fittings. Various inserts arrangements are available to accommodate the required voltage and current needs. Mating connectors should be class E.

(2) Class K Cable Connectors. This class of connectors conforms to Specification MIL-C-5015B. This connector is recommended where it is necessary to maintain electrical continuity for a limited time, even though the connector is subjected to continuous flame. These connectors will maintain electrical continuity when exposed to a 2000° F flame for a minimum of five minutes. For optimum operation, mating connectors should be class K. Class K connectors, having various contact configurations to accommodate various current and voltage requirements, are available from Cannon Electric Company.

(3) Hermetically Sealed Connectors. This class of connectors provides a hermetic seal. Leakage rate will not exceed one micron per cubic foot per hour at a pressure differential of one atmosphere, as tested on a mass spectrometer. The type GS connectors, as manufactured by Cannon Electric, meet the above leakage requirements, and are satisfactory up to 1000°F. The body and contact material is steel with an electro-tin cadmium finish. Pin sealing is accomplished by means of a compression glass seal. Various contact configurations are available to accommodate the required voltage and current needs. The mating connector must have resilient insert material to accommodate pin misalignment.

This class of cable connector is recommended as the best single class to meet all cable connector requirements of this project.

b. Rack and Panel Connectors. The rack and panel connectors being considered here are available in both standard type and hermetically sealed type, and are to be used accordingly. These types of connectors are used in subchassis plug-in applications. Winchester Electric type MRE and HMRE Connectors, U.S. Component Co. type M1 and HM1 connectors, DeJur-Amsco Corporation type 20 and H20 connectors are interchangeable, and are the recommended types. These connectors have a mineral filled melamine which meets the 125°C requirement. Specification MIL-C-8484 (USAF) is the applicable specification. A variety of contact arrangements are available to provide for various voltage requirements. However, it is recommended that connectors with greater than 26 pins not be used. The connectors should be placed so that the direction of connector insertion is perpendicular to the normal axis of flight of the main assembly. This places shear forces on the pins, rather than an axial "in-out" force in the direction of insertion. To assist in alignment when mating, the body of half of the connector assembly should "float". In no case is it recommended that the guide pins and guide sockets be used as current carrying conductors.

6. Receiving Type Tubes

a. General Recommendations. All tubes should be selected from MIL-STD-200C listing of Guided Missile Receiving Type Tubes.

Insofar as possible, all tubes should be mounted so that the tube is at, or nearly at, the sink temperature (i.e. mount tubes in fixtures intimately attached to the frame of the equipment).

Tubes should be de-rated for temperature and voltage to insure long life and reliable performance. De-rating formulae for satisfactory life have been covered in a publication issued by Sylvania Electric Corporation on Air Force Contract AF33(038)-9853. This report covers most of the subminiatures in MIL-STD-200C.

Altitude should not introduce any difficulty as far as high voltage breakdown is concerned. However, if reduced pressure tests indicate difficulty during transition from sea-level to final altitude, it may be necessary to mount subminiature tubes with flexible leads or pot the base.

Tubes should operate satisfactorily under conditions of high shock and vibration. Sufficient work has been performed by all the services and major manufacturers investigating various tube types, especially those in the missile tube listing.

b. Detailed Recommendations. Gas tube type 5727/2D21W should not be used if the ambient temperature exceeds 90°C. Subminiature type 5646 grid control thyratron has a maximum bulb temperature of 125°C. Since ARS operates close to this limit, the tube must be considerably de-rated. All other gas tubes in MIL-STD-200C can safely operate at ambients of 125°C.

All the vacuum tubes on the Guided Missile Tube List are rated for bulb temperatures of 220°C or higher, except for the 5647 (165°C) and the 6203 (180°C).

7. Relays

a. Recommended Construction. The environmental extremes anticipated in ARS applications will restrict the use of relays to three major constructional types, plus several application limitations as outlined. Sources other than those specifically mentioned below may be available for this application but the indicated sources are recommended.

(1) Opposed Plunger. The opposed plunger construction (supplied by A. W. Haydon and Cook Electric Company) has the best resistance to vibration, although there are difficulties in manufacture due to the necessity for precision parts.

(2) Rotary. The rotary construction (supplied by North Electric Co., RCA, Union Switch and Signal, Hi G, Couch, Filtors, and Struthers Dunn Incorporated) has very good properties except for acceleration about its own axis of rotation.

(3) Plunger. The plunger construction (supplied by Allied Control Company, U.S. Relay, and Price Electric Company) can potentially pass the vibration requirements. However, at the present time refinements are still being made in order to

eliminate resonance points at the higher frequencies.

b. Application Limitations.

(1) Dynamic Forces. Vibration tests have been run from 10 to 500 cps at 10g. The results indicate that relays of rotary, plunger, or opposed plunger design are satisfactory for the stipulated range of frequencies. Although vibration tests to 2000 cps are contemplated, no difficulty is expected with these designs.

(2) Temperature. Tests have been run on relay performance at 125°C. Allied Control Incorporated, North Electric, and RCA relays have passed 100,000 operation life tests at this temperature. It might be noted in passing that a relay requires approximately 25 percent more coil power for operation at 125°C than at 85°C. This is due to the increase in coil resistance with temperature. Several vendors have relays which they claim will operate at +200°C.

(3) Reduced Pressure. Since relays in this equipment will be hermetically sealed the primary difficulty with altitude will be the external connections to the relay header. The header terminal spacing must be controlled. Internal pressure is usually one atmosphere of dry air or dry nitrogen. Relay seals are satisfactory up to 260,000 feet. The leakage rate at this altitude can be held to 0.001 micron cubic feet per hour. General Hermetic Seal tests all the relays they seal at 260,000 feet. The leakage rate permissible varies from approximately 0.1 to 0.001 micron cubic feet per hour. A relay will withstand approximately two tenths the sea level high potential at 260,000 feet.

(4) Reliability Aspects. Increased knowledge of the various contact materials and their properties is necessary to

properly derate electrical contacts. Gold alloys such as Bell No. 1 (69% gold, 25% silver, 6% platinum) resist the formation of contact films. It is therefore commonly used in low-level switching. Silver and palladium, used in general applications, form sulfide, nitride, and oxide films which are excessively resistive for dry circuits. In general, moderate deratings of relay contacts affords a significant improvement in the life characteristics of the unit. A 50 percent derating is common for high reliability applications.

Checking such initial characteristics as coil and contact resistance and operate and release values, then performing a 1000-operation test and rechecking the degradation of the aforementioned characteristics has been one of the most effective screening tests. The function of the relay in the circuit must be considered in designing run-in tests. For instance if the operate timing of a relay is important to proper equipment operation it is important that this characteristic be checked in the run-in. Vibration run-in is effective when dealing with certain types of relays (i.e. sensitive and power types). All special requirements which affect the application provide useful screening.

8. Resistors

A large variety of available resistor types can perform satisfactorily under the anticipated dynamic forces and environmental conditions. However, the more common resistor types, such as fixed composition, variable composition, and variable wire-wound (low power and precision) are not suitable for the anticipated environmental extremes. A brief summary of the various available resistor types, recommended vendors, wattage derating factor, and mounting techniques required to permit reliable operation, is given in Table 3-1.

For low power fixed resistance applications, it is recommended that accurate, wirewound, 125°C types be used. However, where low volume, light weight, high resistance values, and/or high frequency performance is required, the deposited carbon film type should be substituted. Variable low power resistors will have to be of the high temperature variety, such as Technology Instruments Corporation type RVHI, which is readily available. Variable power resistors should be of the MIL-R-22A wirewound type. Since variable resistors will exhibit dielectric breakdown between 360 and 450 volts when subjected to the anticipated altitude conditions, applied voltages should not exceed 180 volts, unless precautionary measures are taken.

a. Dynamic Force Stress Investigations. As a result of the application of these stresses: high-frequency vibration of 55 to 2000 cps at 10g's constant peak acceleration; mechanical shock of 30 impacts of 50g's, 10±1 millisec duration; constant acceleration of 50g's for five seconds; the following conclusions may be made:

(1) Fixed, Film, High Stability Resistors. The performance of film resistors is not the same for all vendors. Samples of two-watt rating will not perform satisfactorily under high-frequency vibration conditions, unless the bodies are clamped. All other wattage sizes may be mounted by their wire leads at 0.25 inch from the bodies.

(2) Fixed, Wirewound, Accurate Resistors. All resistors of this type will perform both mechanically and electrically in a satisfactory manner.

(3) Fixed, Wirewound, Power Resistors. No transient electrical conditions (opens, shorts, or large resistance changes) are expected. Electrical changes will be less than 0.2 percent.

(4) Variable, Wirewound, Power Resistors. Resistance changes as great as 10 percent can be expected when these resistors are subjected to high frequency vibration.

(5) Variable, Wirewound, (Trimmer, and Precision) Resistors. External mechanical damage to these resistors will be negligible. However, the internal parts will vibrate excessively. Accordingly, this general type of precision potentiometer is not considered suitable for ARS environments. Development of an improved type is indicated.

9. Semiconductor Rectifiers and Diodes

Since the maximum operating temperature of germanium devices is 85°C, only silicon rectifiers will be considered here.

a. Silicon Junction Rectifiers. In general, all silicon rectifiers are able to withstand the required temperature and pressure conditions. The type of mounting will determine the ability to withstand vibration and shock as follows:

(1) Axial Lead Types. ("Top Hat" style 1N537, for example) This type must be potted to obtain maximum resistance to shock. Normal lead-mounting probably will not suffice.

(2) Stud Mounted Types. (JAN 1N 253, for example) This type is adequately secured by the mounting stud.

(3) Clip Mounted Types. (1N543, for example) This type is probably adequately secured by the mounting clip.

b. Silicon Junction Diodes. In general, all types of silicon junction diodes are able to withstand the required temperature and pressure conditions. Tolerance to vibration and shock will be provided by the mounting system as follows:

Resistor Types Available	Recommended Vendors	% of Nominal Rating Recommended	Maximum	Recommended Mountin Method
Fixed, Film High Stability (Molded or Hermetically-Sealed Only) MIL-R-10509B, Char. G.	IRC, Texas Instruments, Inc.	15	25	Axial Leads, use 0.25 inch max. lead length.
Fixed, Wire-wound, Accurate MIL-R-93A, Char. A.	Shallcross Daven Sprague	25	35	Axial Leads, use 0.25 inch max. lead length. Lug Leads, use #6-32 screw, lockwasher.
Fixed, Wire-wound, Power MIL-R-26C, Char. G.	Ohmite Sprague, Ward Leonard	30	50	Tab Leads, use side mounting bracket of sufficient strength. Axial Leads, use 0.25 inch max. lead length.
Variable, Wirewound, Power MIL-R-22A, (25 Watts and up)	Ohmite	30	50	Bushing, use mounting nut, 1 lockwasher and anti-rotation pin.
Variable, Wire-wound (types designed for high temperature operation).	Helipot TIC Waters	15	25	Bushing, use mounting nut, lockwasher and anti-rotation pin.

TABLE 3-1

(1) Subminiature Axial Lead Type. (1N461, for example) This type is best supported by potting or by printed circuit boards. Lead mounting (no test experience available) may be adequate because of the very low mass.

(2) Single-Ended Types. (1N200, for example) It is necessary that the can be secured rigidly. This can be done by potting, soldering of the can to the printed circuit board, or by securing a clip or strap to the printed circuit board. Lead mounting alone cannot be used.

10. Switches

Since the application is such as to prevent the possibility of manually operating switches after the system has been launched, this discussion will not include toggle or rotary switches or any actuators which require manual operation.

The primary environmental condition which may cause difficulty is the high altitude. Very little information is available on the derating of switches for use at 120,000 feet. The limited tests performed indicate that at 120,000 feet, switches should be derated to 1/7 of their sea-level voltage rating. If the voltage to be applied is more than 1/9 the sea-level voltage rating of the switch, the unit should first be checked out in a vacuum chamber before it is installed in the equipment.

Many vendors offer a grade of switches which will operate satisfactorily at 125°C. However, this requirement should be specified in the purchase requisition.

a. Pressure Switches. Satisfactory pressure switches are available from many vendors, four suppliers being Barksdale, Cook, United Electric, and Meletron.

b. Thermal Switches. Three suppliers of good thermal switches are Spencer Thermostat, Stevens Manufacturing Company, and Fenwal, Incorporated.

c. Application Aids. The switches should be mounted so as to minimize the amount of vibration and shock they are subjected to. Insofar as possible, they should be mounted so that the axis of acceleration forces lies in a line perpendicular to the path of contact travel. It is further recommended that the switches be shock mounted to minimize the effects of vibration and shock.

11. Tip Jacks

Tip jacks as manufactured by Industrial Products Company, their part numbers 250 and 1400, are recommended. These jacks mount through a 0.25-inch hole. The maximum operating temperature is 400°F and the maximum peak operating voltage 1000 volts. Part number 1400 is the pressurized type jack. Both types are available in white color only.

12. Transformers and Reactors

With anticipated ambient temperatures of 125°C in ARS, transformers and reactors employing classes B and H insulation will be required. Class A insulated transformers and reactors may be expected to operate for 50,000 hours provided the hot spot temperature (ambient plus internal rise) does not exceed 105°C. However, the component life decreases approximately 50 percent with a 10°C rise in hot spot temperature. Accordingly, the life expectancy for class A is considerably less than 10,000 hours.

Class B insulation has a similar life characteristic with 130°C being the critical temperature rather than 105°C. For transformers or reactors requiring a large internal temperature rise, class H insulation will be necessary. An important consideration in the selection of these transformers is that open core and coil construction provides for cooler operation than similar transformers or reactors sealed in metallic cans.

No difficult problems are anticipated as a result of the unusual vibration and shock requirements. However, some care must be exercised in mechanical designs employing hypersil cores. These units are smaller and more efficient electrically, but because the cores are "C" shaped and the material grain oriented, specially designed brackets may be necessary.

Excluding possible radiation effects, no other problems are anticipated.

13. Transistors - Germanium and Silicon

Temperature requirements for ARS preclude the use of germanium transistors due to their upper temperature limits, which range between 75°C and 105°C. Our experience indicates that only marginal operation can be expected at junction temperatures in excess of 85°C. Transistor junction temperature is the sum of the ambient temperature plus the temperature rise due to power dissipation at the junction.

Transistors employing silicon are capable of operating from -65° to +200°C junction temperature. The technology of silicon transistors, however, is not as advanced as germanium. Supplies of adequately pure raw materials are very limited, and fabrication techniques require considerable refinement. Consequently, the characteristics of the available transistors are electrically inferior to similar germanium transistors in the temperature ranges in which germanium is capable of operating.

Several major development contracts have been let by the Defense Department to allēviate the present situation.

a. Sealing. All transistors for military applications should be hermetically sealed, preferably by techniques not employing solder fluxes. Sealing eliminates moisture and other contaminents which are capable of impairing or destroying the transistor, when present even in small quantities. Hermetic seals will also facilitate operation in low pressure or vacuum, humidity, and corrosive atmospheres. Transistors are generally used with low enough potentials, so that breakdown should not a problem.

b. Vibration and Shock. The transistor generally has small mass and size, and no moving parts; hence, it can withstand high-g shock, vibration or centrifugal forces with no deleterious effects. 10 to 20g vibrations up to 5000 cycles have produced no failures, and 500g shock and 20,000g centrifugal force are within the range of good low power units. Higher power units (from 2 to 10 watts) are larger in size and cannot take this high acceleration, although no difficulty is anticipated on shock and vibration fatigue.

c. Radiation. For low intensity radiation the can acts as a sufficient shield and is effective in reducing more intense radiations. High energy radiation, such as cosmic, is capable of producing both noise pulses and electrical characteristic changes when present in sufficient quantities. Pending verification by test or published data, it is felt that flux densities will not be high enough to cause this sort of damage. Larger junction area and higher power transistors will be more susceptible to this sort of damage than high frequency and low power units.

d. Reliability Criteria. The level and stability of the leakage current (I_{co}) as a function of time are good measures of life expectancy. No drift of I_{co} is permissible. Aging transistors at high temperatures has the effect of stabilizing the units. One company cycles silicon units from -55° to $+150^{\circ}C$ four or five times, holding the temperature at the limits for a minimum of 30 minutes. Additional aging of all units would insure that the differences in procedure from vendor to vendor would be minimized.

e. Derating. If the device is properly (conservatively) rated, derating of voltage, current or power dissipation will not improve life expectancy characteristics measurably. Caution must be exercised in operating transistors at their upper temperature ratings, since high temperature will seriously degrade transistor life.

f. Stability. Temperature stability of the circuit in which the transistor is used is an important consideration (probably the most important) in insuring long life under various temperature conditions. This points to the necessity for efficient heat transfer and adequate heat sinks. It also emphasizes proper circuit design.

g. Vendor Qualification. Certain vendors are known to be more conservative in rating their products than others. This variation is due in large measure to incomplete information in the industry on the effects of rating on life. Because of this, considerable differences in degree of conservatism can be expected within a single vendor's line of transistors. Comprehensive tests are required to standardize a uniform rating system.

14. Tube Shields

Heat-dissipating electron tube shields, as manufactured by International Electronics Research Corporation (their types T6 and T5), are recommended for the seven and nine-pin miniature tubes. These shields provide excellent heat dissipation qualities and provide vibration protection for the tube, with a resultant increase in tube life.

C. SURVEY OF NEW MATERIALS

1. Improved Dielectrics

Capacitors and other electrical components may benefit from the following materials that show promise for use as dielectrics.

1) Gaseous dielectrics such as sulphur hexafluoride and fluorocarbons at two to three atmospheres.
2) Fluorinated liquid dielectrics.
3) The following solid dielectrics:
   - a) Polyester and mylar (these are already in use, but improvement is anticipated.)
   - b) Lanosterol (recovered from wool fat), which melts at 141°C.
   - c) Synthetic quartz.
   - d) Experimental materials including fused silica paper, aluminum silicate paper, reconstituted mica, hot pressed synthetic mica, phosphate bonded talc, ferroxcube ceramics, ferroelectric ceramics.
4) Impregnants such as chlorinated indans.

Investigations are in progress leading to methods of fabricating silicon with increased purity for transistor use. The lower carrier mobility of silicon as compared with germanium at 25°C makes it a necessary choice only because of its wider temperature range. It is probable that silicon may give way to some new material which has optimum operating characteristic through a wider temperature range. Carbon (diamond) is being evaluated for transistor application.

Considerable effort is being expended by the industry to produce reliable precision metal film resistors. Future phases of the ARS program may be able to utilize the improved miniaturized resistors.

Switch contact, brush and rotating seal wear, as well as long, trouble-free performance of motor bearings are highly dependent upon a highly inert, stable lubricant which can be exposed to ambient conditions without evaporation loss. To date, silicone polymers have been most suitable, although their lubricity or "oiliness" is not comparable to petroleum products. A new type silicone oil and grease has been developed by General Electric Company for which boundary lubrication properties equivalent to petroleum products is claimed (G.E. Versilube). Several companies also are currently developing extremely stable lubricants from chlorofluorocarbon compounds, capable of continuous operation up to 265°C.

Recent developments of ceramic face rotating seals promise positive shaft sealing for long periods without lubrication.

D. HIGH-VACUUM TESTS ON CAPACITORS

1. Types and Quantities Tests

As a result of a survey of the effects of the ARS environmental conditions, a list was compiled of those components thought to be most capable of surviving such conditions. The capacitors used in these high-vacuum tests were among those so listed. Non-availability of some types in the time allotted for this test limited the quantity and degree of testing. The following types and quantities of capacitors were employed for these tests:

Subminiature Type CP-05		Paper	Bathtube Single Double Units; Type CP-53			Tantalum Foil		
Qty.	MFD.	V.Rating	Qty.	MFD.	V. Rating	Qty.	MFD.	V. Rating
6	.068	400 V	12	.25	600 V	3	9	75 V
6	.15	200 V	6	1	600 V	3	36	100 V
6	.22	400 V	6	2	600 V			
6	.47	200 V						

2. Test Procedures

All capacitors were measured initially in room ambient conditions. The 1, 2, 9 and 36 microfarad capacitors underwent capacity measurements at a frequency of 60 cps; the remaining capacitors were measured at a frequency of 1000 cps. All capacity measurements were made on General Radio capacity-measuring equipment. Initial values of insulation resistance were obtained by means of a Bruel and Kjaer megometer type 3423. Pictorial diagrams are presented with the data indicating the connections for such measurements. Oil leakage was observed by means of an ultraviolet light employed in a dark room, the oil having the property of appearing an off-white under such light.

The capacitor testing was divided into two parts, all capacitors being subjected to both parts and with the same type measurements recorded after each part as recorded initially.

The first part of the testing consisted of determining the minimum magnitude of voltage required to break down the terminal-to-case spacing and determining the effects upon the capacitors of two hours at a pressure of 10^{-4}mm of Hg. Voltage breakdown as a function of ambient air pressure and of element geometery and spacing was not tested. The geometery of the capacitors is fixed by their specifications; our tests would indicate actual magnitudes of voltages required to cause breakdown in practical capacitors.

A bell-jar vacuum chamber was used that was capable of being evacuated until an internal ambient pressure of 10^{-4}mm of Hg was reached. Calibration of the vacuum chamber pressure was available only from 10^{-2} to 10^{-4}mm of Hg.

The can and the common or negative terminal of the capacitor were connected together and grounded. A d-c voltage of half the rated working voltage was applied between the positive terminal and ground at sea level pressure in the vacuum chamber. The pressure in the chamber was then reduced and the leakage current was monitored by an RCA ultra sensitive microammeter (WV-84). If no leakage occurred the pressure was returned to sea level pressure and the voltage was increased in 25-volt increments until leakage occurred. For each change of voltage the vacuum chamber went through a complete cycle from sea level pressure to 10^{-4}mm of Hg.

Upon completion of the measurement of minimum breakdown voltage values, all capacitors were left in the bell jar in an ambient pressure of 10^{-4}mm of Hg for a period of two hours. This ended the first part of the testing.

The second part of the testing subjected the capacitors to high case temperatures in addition to the voltage and vacuum conditions. With the capacitors at an ambient pressure of 10^{-4}mm of Hg the case temperature was caused to rise to a value of 125°C (obtainable by means of radiation and conduction through the use of a heating element and metal plate within the chamber). Capacitor case temperatures were monitored by a thermocouple and calibrated bridge. Rated voltage was applied when the vacuum and temperature conditions just described were established. The capacitors remained under such conditions for a period of 15 minutes, after which they were returned to room ambient conditions and allowed to cool.

3. Results

There were no changes in capacity or insulation resistance values from those recorded initially on any capacitor during the "first part". Ultraviolet light examination revealed no oil leakage prior to or after this part. A chart follows listing the range of minimum breakdown voltage values obtained for the particular type capacitors. In no instance was the applied voltage increased to a value greater than twice the rated value.

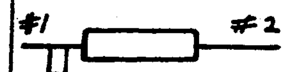
Capacitor	Voltage Breakdown Range
Type CP05 --- (400V rating)	425V to 520V
Type CP05 --- (200V rating)	No breakdown up to 400V
Type CP53 --- (600V rating)	400V to 450V
Tantalum --- (75 V rating)	No breakdown up to 150V
Tantalum --- (100V rating)	No breakdown up to 200V

The second part testing revealed no capacitor failures although a change in insulation resistance was recorded as noted on the data sheets.

It appears that these capacitors can function properly under the conditions of vacuum and temperature described, providing voltage derating is imposed upon those units rated at 600 volts.

TYPE CP05 .22 MFD. 400 V. SUB-MIN. PAPER	INITIAL READINGS OF CAPACITORS			AFTER 2 HRS. IN HIGH VACUUM 10^{-4} MM Hg.			AFTER TEMP & RATED VOLTAGE AT HIGH VACUUM 10^{-4} MM Hg.			MINIMUM BREAKDOWN VOLTAGE AT CORRESPONDING VACUUM
TYPE #	CAP. MFD. SINGLE SECTION	MEGOHMS. INS. RES. # 1	# 2	CAP. MFD. SINGLE SECTION	MEGOHMS. INS. RES. # 1	# 2	CAP. MFD. SINGLE SECTION	MEGOHMS. INS. RES. # 1	# 2	VOLTS D. C.
1450	.2014	$>100\times10^5$	$>100\times10^5$	.2014	$>100\times10^5$	$>100\times10^5$	.2032	$>100\times10^5$	$>100\times10^5$	520 V.
1451	.2055	"	"	.2055	"	"	.2064	"	"	520 V.
1452	.2002	"	"	.2002	"	"	.2008	"	"	460 V.
1453 **	.2033	"	"	.2033	"	"	.2032	"	"	440 V.
1454	.2010	"	"	.2010	"	"	.2016	"	"	440 V.
1455	.2073	"	"	.2073	"	"	.2076	"	"	450 V.
.47MFD. 200V.D.C. *										
1456	.4811	$>100\times10^5$	$>100\times10^5$	.4811	$>100\times10^5$	$>100\times10^5$	.4752	$>100\times10^5$	$>100\times10^5$	No Breakdown
1457	.4693	"	"	.4693	"	"	.4716	"	"	"
1458 **	.4740	"	"	.4740	"	"	.4558	"	"	"
1459	.4568	"	"	.4568	"	"	.4607	"	"	"
1460	.4798	"	"	.4798	"	"	.4836	"	"	"
1461	.4456	"	"	.4456	"	"	.4488	"	"	"
.15MFD. 200 V.D.C. *										
1462	.1503	$>100\times10^5$	$>100\times10^5$	.1503	$>100\times10^5$	$>100\times10^5$	.1538	$>100\times10^5$	$>100\times10^5$	No Breakdown
1463	.1506	"	"	.1506	"	"	.1566	"	"	"
1464	.1502	"	"	.1502	"	"	.1530	"	"	"
1465	.1500	"	"	.1500	"	"	.1506	"	"	"
1466	.1503	"	"	.1503	"	"	.1534	"	"	"
1467	.1473	"	"	.1473	"	"	.1482	"	"	"

DRAWING OF SAMPLE



Ins.Res. at 100V. D.C.
1.- To Case
2 - To Case

* Capacitors # 1456 to 1467 inclusive, did not have more thantwice their rated voltage applied
** Temperature in excess of 180°C was accidentally applied to these capacitors causing the solder seal to flow and allowing oil leakage.

TABLE 3-2

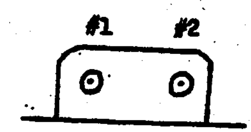
[redacted]

[redacted]

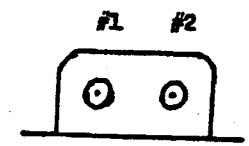
TYPE CP53

BATH TUBS PAPER TYPE TAPE #	INITIAL READINGS OF CAPACITORS CAP. MFD. SINGLE SECTION	MEGOHMS INS. RES. #1	MEGOHMS INS. RES. #2	AFTER 2 HRS. IN HIGH VACUUM 10^{-4} MM Hg. CAP. MFD. SINGLE SECTION	MEGOHMS. INS. RES. #1	MEGOHMS. INS. RES. #2	AFTER TEMP & RATED VOLTAGE AT HIGH VACUUM 10^{-4} MM Hg. CAP. MFD. SINGLE SECTION	MEGOHMS. INS. RES. #1	MEGOHMS. INS. RES. #2	MINIMUM BREAKDOWN VOLTAGE AT CORRESPONDING VACUUM VOLTS D. C.
1 MFD. 600V. D.C.										
1512	.9880	1.4×10^5	2.3×10^5	.9880	1.4×10^5	2.3×10^5	.890	$>1\times10^5$	$>1\times10^5$	425 V.
1513	1.005	3×10^5	3.6×10^5	1.005	3×10^5	3.6×10^5	.895	"	"	400 V.
1514	.9625	1.2×10^5	1.5×10^5	.9625	1.2×10^5	1.5×10^5	.872	"	"	400 V.
1515	.9765	1.4×10^4	1.3×10^5	.9765	1.4×10^4	1.3×10^5	.880	"	"	400 V.
1516	.9643	1.2×10^4	1.3×10^5	.9643	1.2×10^4	1.3×10^5	.875	"	"	400 V.
1517	.9714	2.8×10^5	3.4×10^5	.9714	2.8×10^5	3.4×10^5	.880	"	"	420 V.
2 MFD. 600V. D.C.										
1518	2.07	2.8×10^4	2.8×10^4	2.07	2.8×10^4	2.8×10^4	2.06	2.2×10^4	2.2×10^4	400 V.
1519	2.15	1.9×10^4	2×10^4	2.15	1.9×10^4	2×10^4	2.15	2.0×10^4	2.0×10^4	400 V.
1520	2.11	3.2×10^4	3.4×10^4	2.11	3.2×10^4	3.4×10^4	2.10	2.6×10^4	2.6×10^4	400 V.
1521	2.14	2.2×10^4	2.3×10^4	2.14	2.2×10^4	2.3×10^4	2.15	2.0×10^4	2.0×10^4	400 V.
1522	2.02	2.3×10^4	2.2×10^4	2.02	2.3×10^4	2.2×10^4	2.01	1.9×10^4	1.9×10^4	400 V.
1523	2.16	1.3×10^4	1.3×10^4	2.16	1.3×10^4	1.3×10^4	2.17	2.4×10^4	2.4×10^4	400 V.

DRAWING OF SAMPLE



#1 - To Case
#2 - To Case

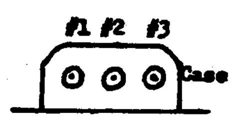


#1 - To Case
#2 - To Case

TABLE 3-2 (Continued)

[redacted]

TYPE CP53 2X.25 MFD 600V. D.C. BATH TUBS PAPER TYPE	INITIAL READINGS OF CAPACITORS					AFTER 2HRS. IN HIGH VACUUM 10^{-4} MM Hg					AFTER TEMP & RATED VOLTAGE IN HIGH VACUUM 10^{-4} MM Hg.					* MVBD.
	CAP.	CAP.	INSULATION RES.			CAP.	CAP.	INSULATION RES.			CAP.	CAP.	INSULATION RES			ACV.
	MFD. 1st	MFD. 2nd	MEGOHMS.			MFD. 1st	MFD. 2nd	MEGOHMS.			MFD. 1st	MFD. 2nd	MEGOHMS			VOLTS
TAPE #	SECTION	SECTION	#1	#2	#3	SECTION	SECTION	#1	#2	#3	SECTION	SECTION	#1	#2	#3	D.C.
1500	.2492	.2501	$6X10^5$	$6.5X10^5$	$7X10^5$	.2492	.2501	$6X10^5$	$6.5X10^5$	$7X10^5$	.2512	.2497	$>2X10^5$	$>2X10^5$	$>2X10^5$	425 V.
1501	.2477	.2464	$6X10^5$	$7.5X10^5$	$8X10^5$	.2477	.2464	$6X10^5$	$7.5X10^5$	$8X10^5$	.2481	.2467	$2X10^5$	$2X10^5$	$2X10^5$	440 V.
1502	.2452	.2500	$5.5X10^5$	$6.5X10^5$	$7X10^5$	.2452	.2500	$5.5X10^5$	$6.5X10^5$	$7X10^5$	.2453	.2506	"	"	"	440 V.
1503	.2602	.2580	$5X10^5$	$6X10^5$	$6X10^5$	.2602	.2580	$5X10^5$	$6X10^5$	$6X10^5$	.2608	.2586	"	"	"	440 V.
1504	.2406	.2408	$6X10^5$	$7X10^5$	$8X10^5$	.2406	.2408	$6X10^5$	$7X10^5$	$8X10^5$	.2410	.2414	"	"	"	450 V.
1505	.2504	.2647	$5.5X10^5$	$6.5X10^5$	$7.5X10^5$	.2504	.2647	$5.5X10^5$	$6.5X10^5$	$7.5X10^5$	.2546	.2670	"	"	"	420 V.
1506	.2624	.2456	$5.5X10^5$	$7X10^5$	$8X10^5$	.2624	.2456	$5.5X10^5$	$7X10^5$	$8X10^5$	.2630	.2460	"	"	"	425 V.
1507	.2745	.2796	$6X10^5$	$7.5X10^5$	$3X10^5$	.2745	.2796	$6X10^5$	$7.5X10^5$	$8X10^5$	.2752	.2803	"	"	"	440 V.
1508	.2653	.2495	$5X10^5$	$6X10^5$	$6.5X10^5$	.2653	.2495	$5X10^5$	$6X10^5$	$6.5X10^5$	.2654	.2536	"	"	"	440 V.
1509	.2906	.2846	$6X10^5$	$7.5X10^5$	$8.5X10^5$	.2906	.2846	$6X10^5$	$7.5X10^5$	$8.5X10^5$	.2915	.2856	"	"	"	425 V.
1510	.2580	.2728	$7.5X10^5$	$9X10^5$	$10X10^5$	.2580	.2728	$7.5X10^5$	$9X10^5$	$10X10^5$	.2577	.2739	"	"	"	425V.
1511	.2534	.2540	$6X10^5$	$8X10^5$	$7X10^5$	.2534	.2540	$6X10^5$	$8X10^5$	$7X10^5$	.2539	.2544	"	"	"	420 V.

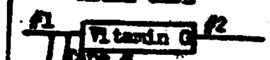
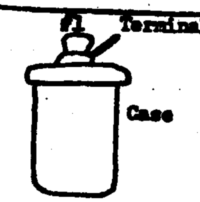
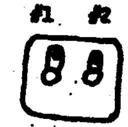


1 - To case
2 - To Case
3 - To Case

* Abbreviation for minimum voltage breakdown at corresponding vacuum.

TABLE 3-2 (Continued)

[redacted]

TYPE CP05 .068 MFD. 400 V.DC SUB-MIN. PAPER TAPE #	INITIAL READINGS OF CAPACITORS CAP. MFD. SINGLE SECTION	MEGOHMS. INS. RES. # 1	# 2	AFTER 2 HRS. IN HIGH VACUUM 10^{-4} MM Hg. CAP. MFD. SINGLE SECTION	MEGOHMS. INS. RES. # 1	# 2	AFTER TEMP & RATED VOLTAGE AT HIGH VACUUM 10^{-4} MM Hg. CAP. MFD. SINGLE SECTION	MEGOHMS. INS. RES. # 1	# 2	MINIMUM BREAKDOWN VOLTAGE AT CORRESPONDING VACUUM VOLTS D. C.	DRAWING OF SAMPLE
1468	.0700	>100x10⁵	>100x10⁵	.0700	>100x10⁵	>100x10⁵	.0703	>100x10⁵	>100x10⁵	440 V.	METAL CASE  #1 Vitamin G Tape # #2 Ins. Res. at 100V.D.C. # 1 - To case # 2 - To case
1469	.0678	"	"	.0678	"	"	.0679	"	"	440 V.	
1470	.0700	"	"	.0700	"	"	.0706	"	"	440 V.	
1471	.0672	"	"	.0672	"	"	.0677	"	"	425 V.	
1472	.0706	"	"	.0706	"	"	.0709	"	"	425 V.	
1473	.0679	"	"	.0679	"	"	.0680	"	"	440 V.	
Tantalum											
35MFD. 100 V.D. C. *											 #1 Terminal Case Tantalum #1 - To case
1524	39.20	20	—	39.20	20	—	39.2	15	—	No breakdown	
1525	40.07	20	—	40.07	20	—	40.6	12	—	"	
1526	39.50	20	—	39.50	20	—	39.5	10	—	"	
9 MFD. 750 V.D. C.*											 #1 #2 Case Tantalum #1 - To case #2 - To case
1527	9.07	16 16	16	9.07	16	16	9.1	7	3	No breakdown	
1528	9.34	20	14	9.34	20	16	9.6	4	8.5	" "	
1529	9.57	25	20	9.57	25	20	Not	Used		" "	

* Capacitors # 1524 to 1529 inclusive, did not have more than twice their rated voltage applied.

TABLE 3-2 (Continued)

[redacted]

E. ADDITIONAL VOLTAGE BREAKDOWN TESTS

In addition to the environmental testing of capacitors it was deemed desirable to obtain an indication of the minimum breakdown voltages of other components. Time did not permit an elaborate test program but facilities were available to allow such measurements to be made in an ambient air pressure that allows the minimum voltage arc-over to occur.

In general, the procedure for obtaining minimum voltage breakdown values was the same for all components so tested. The procedure consisted of applying the rated magnitude of voltage (if known) between the two points of interest (described below for each component tested), at room ambient air pressure. Voltage breakdown points were indicated by means of an RCA ultrasensitive microammeter type, WV-84. Voltage breakdown was forced upon each component by two means. First, with voltage applied as above, the ambient air pressure was reduced either until voltage breakdown occurred or 10^{-4}mm of Hg was reached. If no breakdown was indicated the pressure was increased back to the room ambient value and the applied voltage increased in increments of 25 volts and the pressure reduced till breakdown occurred. As a point of interest, the ambient air pressure allowing for minimum breakdown voltage between parallel, plane electrodes of any spacing is 4 ± 2mm of Hg, roughly equivalent to an altitude of 120,000 feet.

2. Results

a. Potentiometers. A group of 16 potentiometers including wirewound and composition types and of the miniature and standard sizes were subjected to voltage-breakdown measurements with the results as shown in Table 3-3. For each potentiometer the d-c test voltage was applied between its three terminals (all connected together) and its shaft. The potentiometers were mounted on an aluminum panel.

b. Tube Sockets. Six each of the seven-and nine-pin miniature, steatite sockets were measured. The test voltage was applied between all adjacent terminals of each socket, the wiring being so arranged as to prevent breakdown between connecting wire rather than between terminals as desired. In all instances the value of breakdown voltage was within the limits of 400 and 425 volts, dc.

c. Cable Connector. Considering the possible need for interchasis connections, one 35-terminal AN type environmental-proof, type E connector was available for voltage-breakdown measurements. The connector was an Amphenol hermetically sealed type with a specified breakdown rating of 500 volts, rms, between any two adjacent terminals.

Tests showed that 460 volts, dc, were required to cause breakdown between adjacent terminals or between the metal shell and the two terminals closest to the metal shell.

d. HF Cables and Connectors. Six small lengths of coaxial cable, three with connectors and three open ended, were measured for minimum voltage breakdown values. All were checked first with a d-c voltage applied and secondly with 60 cycle ac. None gave indication of arcover with 480 volts dc applied. However, all broke down at 500 volts dc. The a-c, rms values for breakdown are given below with the specific cable. Application of the test voltage, both dc and ac, was made between the inner and outer coaxial conductors at one end of the cables while submerged in oil. The remaining end of the cables were in the ambient pressure as mentioned earlier.

This procedure with the cables was necessary to insure that breakdown would not occur at the point of test voltage application.

TAPE NO.	COMPONENT	CABLE TYPE	CONNECTOR TYPE	MEASURED BREAKDOWN VOLTAGE
1166	Coaxial Cable	RG-158/U (Nylon Jacket)		400 V RMS
1167	Coaxial Cable	RG-158/U (Kel-F Jacket)		400 V RMS
1168	Coaxial Cable	RG-158/U (Teflon Jacket)		360 V RMS
1169	Cable Assembly	Amphenol 50 ohm 60 mil DOD	Dage CBSN 1-352	320
1170	Cable Assembly	Amphenol 50 ohm	Dage CBSN 1-317-1	320
1171	Cable Assembly	Amphenol 93 ohm 60 mil DOD	Auto CBWT RF-0280	400

TAPE #	TYPE	VENDOR	NUMBER	MEASURED BREAKDOWN VOLTAGE AT CRITICAL PRESSURE VOLTS	SPECIFIED MIN. BREAKDOWN VOLT. AT SEA LEVEL PRESSURE VOLTS	SPECIFIED MIN BREAKDOWN VOLT. AT 50,000 FEET VOLTS
1150	Variable Composition	Allen Bradley	Type J	420	900	450
1151	Variable Composition	Clarostat Sub-min.	Type 48	400	900	350
1152	Variable Wire Wound	I. R. C.	Type 2W	380	900	450
1153	Variable Wire Wound	Clarostat	Type 43	260	900	450
1154	Variable Composition	C. T. S.	Type 35	360	900	450
1155	Variable Wire Wound	Centralab	Model V	380	900	450
1156	Variable Composition	C. T. S.	Type 35	360	900	450
1157	Variable Composition	Allen Bradley	Type J	340	900	450
1158	Variable Composition	Clarostat	Type 53	360	900	450
1159	Variable Composition	Clarostat Min.	Type 47	360	900	450
1160	Variable Composition	Clarostat sub-min.	Type 48	400	900	450
1161	Variable Wire Wound	Waters "Aerohm sub.-min.	AP 1/2	460	900	350
1162	Variable Composition	Clarostat min.	Type 47	360	900	450
1163	Variable Composition	Centralab sub-min.	Model 3 Radiohm	400	900	450
1164	Variable Wire Wound	Tech.Instr.Corp.sub-min.	RV 7/8	440	900	350
1165	Variable Wire Wound	Clarostat sub-min.	Type 49	380	900	450

TABLE 3-3

CHAPTER IV

PERFORMANCE OF BATTERY POWER SUPPLIES

A. REQUIREMENTS FOR BATTERIES TO BE USED IN ARS VEHICLES

Early vehicles will require power for transponders, clock and order storage, a television camera, a television communication transmitter, attitude stabilization, and scientific apparatus.

1. Reliability

Reliability is of prime importance. Once in orbit the vehicle becomes entirely dependent on the batteries for its operation. Early vehicles will not be able to recharge batteries; when the batteries are exhausted the vehicles will not be able to supply any information to the ground stations and will be without attitude stabilization. Later vehicles are expected to be able to charge the batteries once during each orbit while on the side toward the sun. This arrangement will allow a smaller battery to be used, but its dependence on the charging facility may make it less reliable than where batteries alone are used. The smallest possible battery supply would need enough capacity to carry the peak power load and to provide sufficient watt-hours to last between charge cycles. Such a battery would provide the vehicle with power for only one orbit after the charging facility had failed. From the standpoint of obtaining the greatest reliability the battery capacity should be as high as weight allowance will permit. This would provide the longest possible time of operation in the event of failure of the charging facility. Another fact that will affect reliability is that when either solar battery or thermocouple charging is used it becomes necessary to provide some sort of disconnecting device to prevent the battery from discharging into the charger during the dark periods.

The cells which comprise the battery power supply should be arranged to provide the greatest possible redundancy. For example, connecting the cells in multiple strings in parallel rather than all in series. Reliability requirements for satellite operation are several orders of magnitude greater than that being attained with current airborne electronics equipment. It is generally conceded that reliability and simplicity usually go together. It follows that considerable emphasis must be placed on keeping the system as simple as possible.

2. Importance of High Watt-Hours per Pound Ratio

In earlier vehicles no charging facility will be provided and the capacity of the battery will determine how long the vehicle will operate. The payload of earlier vehicles will be drastically limited in order to insure sufficient fuel capacity for ascent. Weight of batteries allowed will thus be very limited and in order to provide the longest operation, it will be necessary to use batteries having a high watt-hours per pound figure. Any increase in this figure will provide longer operation of the vehicle

3. Temperature

The batteries must be able to operate over as wide a range of temperatures as possible because exact figures for the environmental temperature have not been measured. Calculations show that the average temperature to be expected within the container housing the batteries will vary between the limits of approximately +50°C at the completion of the ascent and approximately +27°C after the fifteenth revolution around the earth. Thereafter, the indication is that this value of +27°C will remain constant. In the calculations it was assumed that no heat would be generated in the batteries.

4. Vacuum

Operation in a vacuum is necessary and batteries which will not provide satisfactory operation under this condition for their normal life will require some sort of pressurized container. Most batteries give off gas and if a pressurized container is used it must be provided with a pressure relief valve. The pressure must not be allowed to become low enough to approach the value at which the battery electrolyte will boil. For example, the boiling point of a 44 percent solution of KOH at 760 mm of Hg is 130°C and at 50,000 foot altitude the boiling point for this solution is reduced to 64°C. The reliability of the complete pressurized system must be as high as possible.

5. Shock and Vibration

It is expected that the greatest acceleration, vibration and shock will be encountered during the ascent of the vehicle. The measurements that have been made thus far indicate that these forces will not be destructive. Acceleration forces are expected not to exceed a steady state value of 10g with an a-c component of 10g up to 1500 cps and having a maximum amplitude at low frequencies below 10 cps. It is expected that the forces encountered in orbit will be insignificant.

6. Gravitational Forces

Once the vehicle is stabilized in its orbital path, centrifugal force will completely nullify the force of gravity. This means that no processes can be utilized which depend on the force of gravity for their operation. An example of such a process is an electromagnetically actuated relay armature which depends on gravitional force for its return to the unenergized position. Perhaps batteries which contain a liquid electrolyte may not function for extended periods in the absence of gravity. Tests of components for the effect of the absence of gravity cannot be made for obvious reasons.

7. Quantity of Batteries Required

For the early type of vehicle, computations have been made to determine the quantity of batteries required. Figure 4-1 shows these data in the form of pounds of batteries versus time for several methods of operation. These figures are based on using a battery which develops 50 watt-hours per pound of weight. Table 4-1 is a tabulation of the various quantities that were compiled to form the basis for Figure 4-1. It should be noted that where the number of cells is shown, the figures are based on a developmental cell which is probably smaller in size than the cell that would actually be used. This tends to make the "number of cells" figure much higher than if a larger size of cell were used. It does not affect the total pounds of battery required since this figure is based on watt-hours per pound.

B. TYPES OF BATTERIES TESTED

Four types of batteries were investigated. These types were chosen on the basis of manufacturer's ratings which indicated possible suitability for satellite operation.

The four types consisted of:

1) RCA; an improved form of dry cell, now in the experimental stage.
2) Mallory; mercury cell
3) Yardney; silvercell
4) Nickel-cadmium cells manufactured under trade names of Voltabloc, Gould, Deac.

This group of the four types of cells is representative of the current types available and includes both rechargeable and non-rechargeable types. Both types are of interest since early ARS vehicles will not have facility for charging batteries while later vehicles will contain solar energy conversion equipment for this purpose. Silvercells may be recharged a limited number of

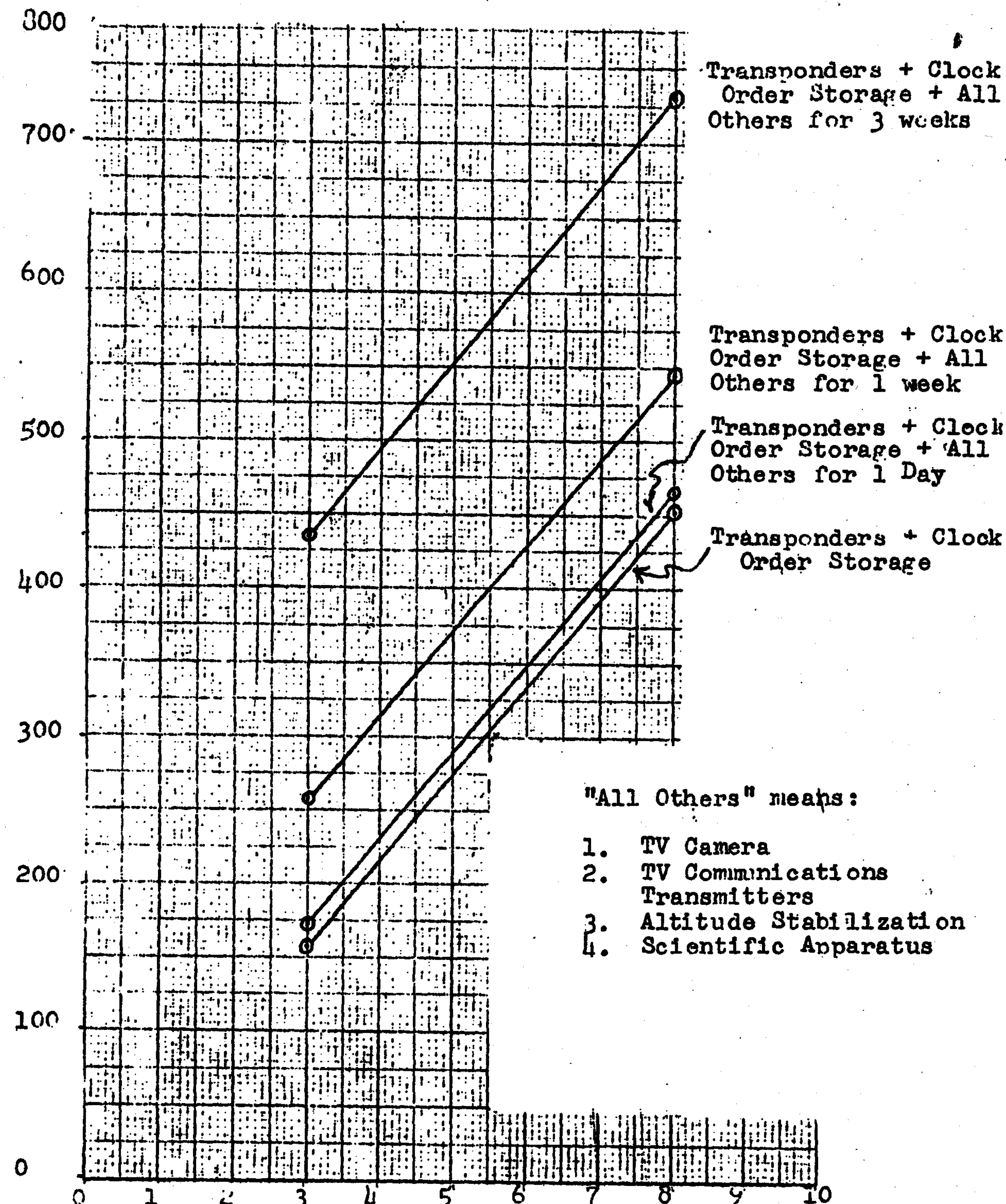


Figure 4-1. Battery Weight vs Time for Several Methods of Operation

[redacted]

TABLE 4-1

ESTIMATE OF BATTERY WEIGHT FOR EARLY VEHICLES

(Based on RCA cells ± 3.3 watt-hrs/cell 50 watt-hrs/pound = 15 cells/pound)

Unit	Peak Watts	Duty Factor	Peak Watts x Duty Factor	Watt-Hrs. for 3 Weeks - (504 hrs)	No. of cells for 3 weeks	Weight of cells for 3 weeks	Watt-Hrs. for 8 weeks - (1440 Hrs)	No. of cells for 8 weeks	Weight of cells for 8 weeks
Two transponders	70	0.194	13.58	6,844	2,073	Pounds 138.2	19,555	5,925	Pounds 395
Clock and Order Storage	2	1.0	2.0	1,008	306	20.4	2,880	872	58.2
TV camera □	7	0.011 ★	0.077	38.8	21 ⊕	1.4 ⊕	110.9	34	2.26
TV communications □ Transmitters	100	0.011 ★	1.1	555	169	11.2	1,584	480	32
Altitude □ Stabilization	25	1.0	25	12,600	3,812	254	36,000	10,909	727
Scientific □ Apparatus	50	0.02	1.0	504	153	10	1,440	437	29

Notes: ★ Based on 1 minute of operation per orbit
⊕ Minimum of 25V required
□ Off after the first period

[redacted]

times and nickel-cadmium batteries may be recharged an indefinite number of times.

1. Manufacturer's Ratings

Tables 4-2 and 4-3 indicate the manufacturer's data on all of the cell types tested. These data were obtained from catalogs except in the case of the RCA cells. For these, no information has been published and the figures have been compiled as the cells were tested. It should be remembered that where figures are given for the performance of batteries, the conditions of load and environment should be specified. Catalog figures often are based on optimum conditions which show the best performance figures. To obtain some idea of the internal resistance of the four types of cells investigated, cell voltage versus load current was plotted as Figure 4-2. These data apply only to the particular size of cell given on the curve. It can be said, however, that the mercury, nickel-cadmium, and silver zinc batteries have lower internal resistance for a given physical size than does the dry cell. Low internal resistance is desirable where high peak load currents are needed but is not important when a suitable load is used.

2. Chemical Reactions in the Cells Tested[1, 2]

a. Mercury Cell. The cathode and depolarizer of the mercury cell is composed of mercuric oxide, HgO, and graphite. The graphite is added to improve the electrical conductivity. The anode is composed of zinc, which is amalgamated to reduce local action. The electrolyte has three constituents, potassium hydroxide, KOH; zincate, K_2ZnO_2; and water. The KOH serves as the conducting medium; the K_2ZnO_2 reduces the gassing; the water takes part in the reaction. The reaction as given in the reference is:

At anode:

$$Zn + 2OH^- \longrightarrow Zn(OH)_2 + 2e \rightleftharpoons ZnO + H_2O + 2e$$

TABLE 4-2

MANUFACTURER'S RATINGS - 3 BATTERY TYPES

	Cell Identity		
	RCA Type C	Mallory Type RM-42R	Yardney Type LR-5
Volts	1.20	1.34	1.50
Amp-Hours	0.18	14.0	7.2 for 0.50 amps.
Watt-Hours	3.3	18.9	10.8
Watt-Hours Per Pound	49.8	51.6	41.9
Weight in Ounces	1.06	5.85	4.13
Dimensions			
Height	2.0"	2.375"	3.00"
Width	---	-----	2.08"
Depth	---	-----	0.80"
Diameter	0.938"	1.190"	----
Volume in Cubic Inches	1.38	2.64	5.05

TABLE 4-3

MANUFACTURER'S RATINGS - ON NICKEL CADMIUM BATTERIES									
	Cell Identity								
	Volta-bloc	Gould Button		D E A C					
	VO4	32B	23B	450D	220D	150DK	120DK	90DK	60DK
Volts	1.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Amp-Hours	4	0.175	0.080	0.450	0.220	0.150	0.120	0.090	0.060
Watt-Hours	5.6	0.262	0.120	0.675	0.330	0.225	0.180	0.135	0.090
Watt-Hours Per Pound	14.9	8.15	9.15	13.5	12.0	10.6	9.27	8.29	11.7
Weight in Ounces	6.0	0.515	0.208	0.795	0.441	0.336	0.304	0.256	0.123
Dimensions									
Height	3 1/32"	--	--	2 5/16"	1 1/2"	--	--	--	--
Width	2 11/32"	11/32"	5/32"	--	--	7/32"	7/32"	5/32"	7/32"
Depth	17/32"	--	--	--	--	--	--	--	--
Diameter	--	1 1/4"	7/8"	17/32"	17/32"	31/32"	31/32"	31/32"	19/32
Volume in Cubic Inches	5.50	0.422	0.094	0.512	0.332	0.162	0.162	0.116	0.0675

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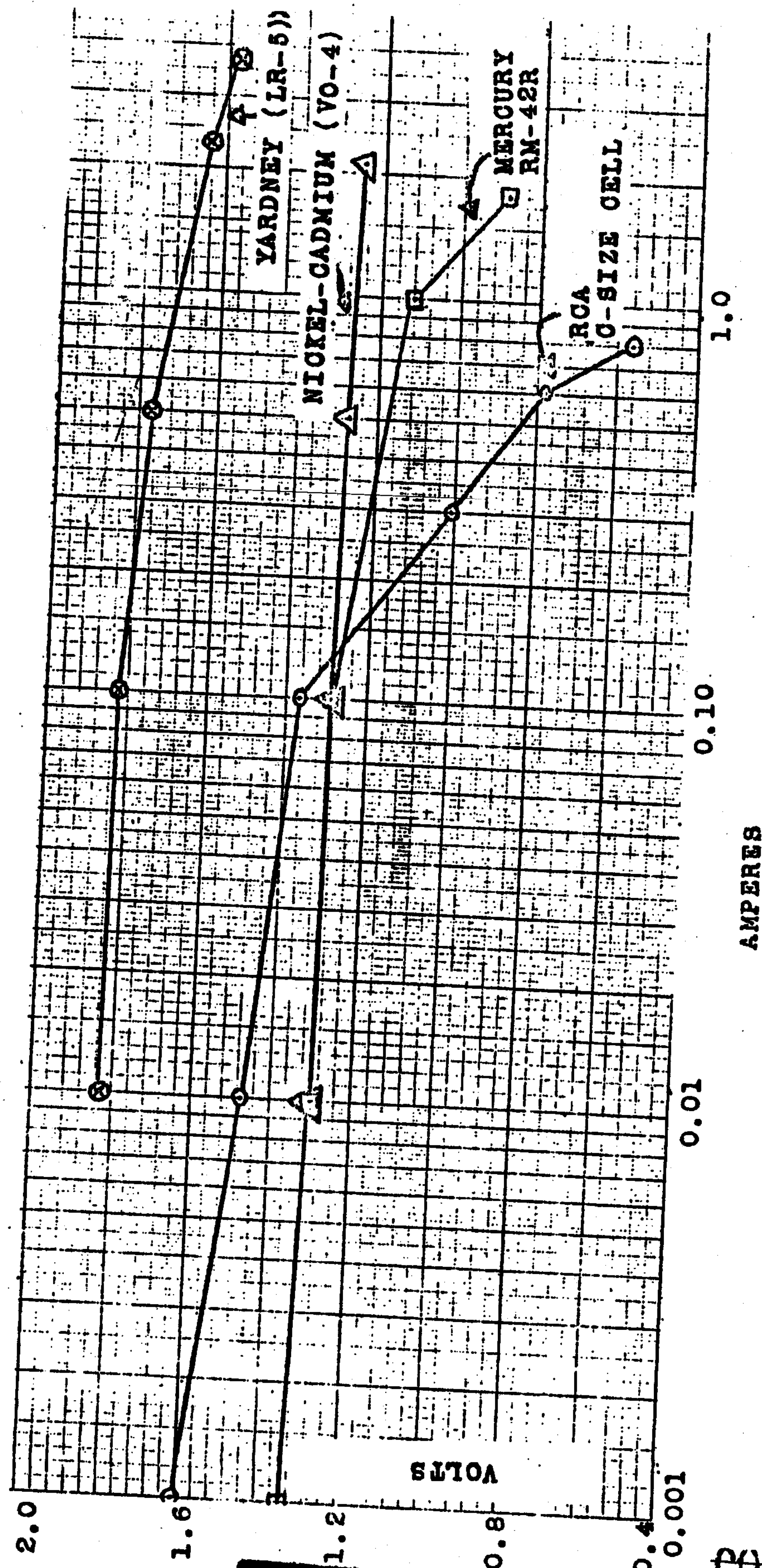

Figure 4-2. Cell Voltage Versus Load Current

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At cathode:

$$HgO + H_2O + 2e \rightarrow Hg + 2OH^-$$

Combined Reaction:

$$\underset{\text{charged}}{Zn + H_2O + HgO} \rightarrow \underset{\text{discharged}}{ZnO + H_2O + Hg}$$

b. Nickel-Cadmium Cell. The anode is cadmium; the cathode is a nickel oxide, Ni_2O_3; the electrolyte is potassium hydroxide, KOH. The exact reaction was not established as of 1955. Two theories were presented in reference 2. They are:

1) $Cd + Ni_2O_3 \rightleftarrows CdO + 2NiO$ (main reaction)

$$\underset{\text{charge}}{Cd + NiO_2} \rightleftarrows \underset{\text{discharge}}{CdO + NiO} \quad \text{(secondary reaction)}$$

2) $$\underset{\text{charge}}{2Ni(OH)_3 \cdot 5H_2O + 2KOH + Cd} \rightleftarrows \underset{\text{discharge}}{2Ni(OH)_2 \cdot 6H_2O + 2KOH + 2H_2O + CdO}$$

c. Yardney - Silvercell. The anode material is zinc; the cathode is either AgO or Ag_2O_2; the electrolyte is KOH. The literature distributed by Yardney (apparently used as source material for reference 2) shows the reaction to be:

$$\underset{\text{charged}}{AgO + Zn + H_2O} \rightleftarrows \underset{\text{discharged}}{Ag + Zn(OH)_2}$$

A more detailed discussion of the silver-oxide battery is available that differs somewhat from the Yardney theory. Reference[1] contains this discussion and gives the following two-stage reaction:

$$Ag_2O_2 + 2KOH + Zn \rightarrow K_2ZnO_2 + H_2O + Ag_2O$$

$$Ag_2O + 2KOH + Zn \rightarrow K_2ZnO_2 + H_2O + 2Ag$$

The two stages offer an explanation of the two-plateau discharge characteristic of the cell. The higher voltage is present during the first stage which involves the Ag_2O_2. The voltage drops when the second reaction is taking place. If the discharge rate is

[1] Primary Batteries - Vinal

[2] Storage Batteries - Vinal

high enough the first level is not noticeable. If the electrolyte is saturated with K_2ZnO_2. ZnO will be formed instead of K_2ZnO_2.

d. RCA Cell. The chemistry of the Type A RCA experimental cell must be considered as company confidential at the present time.

C. TEMPERATURE TESTS

1. Purpose and Conditions

These tests were performed to obtain the voltage versus time characteristic of each cell under load and the total watt-hours per pound of the cell at various temperatures. The loads on the cells were selected so as to discharge the cells in approximately 100 hours. This current drain is greater than that required in the vehicle but this rate was necessary to permit the completion of the tests within a reasonable time. The temperatures for the tests were selected to cover more than the expected temperature range to be experienced in the vehicle. Tests were made at +60°C, +40°C, +22°C (room temperature), +10°C, 0°C, -10°C, and -20°C. Cells tested were RCA/developmental, Mallory/mercury, Yardney/silvercell and the nickel-cadmium cells Voltabloc, Gould and Deac.

2. Test Equipment for Temperature Tests

a. Test Chamber. Except for the room temperature test, all runs in the range -20°C to +60°C were performed in a chamber about four feet long, three feet wide and three feet high. (See Figures 4-3 and 4-4) Specifically designed for use in making hot and cold tests, it was built in three main sections. The largest section, occupying about two-thirds of the total volume, held the specimens under test. Adjacent to this section was a cabinet about half the size of the remaining volume which held the dry ice for the cold runs. The remaining section, located below the ice cabinet, contained a heater and a fan. A special door regulated the circulation between the ice cabinet and the fan. Circulation between

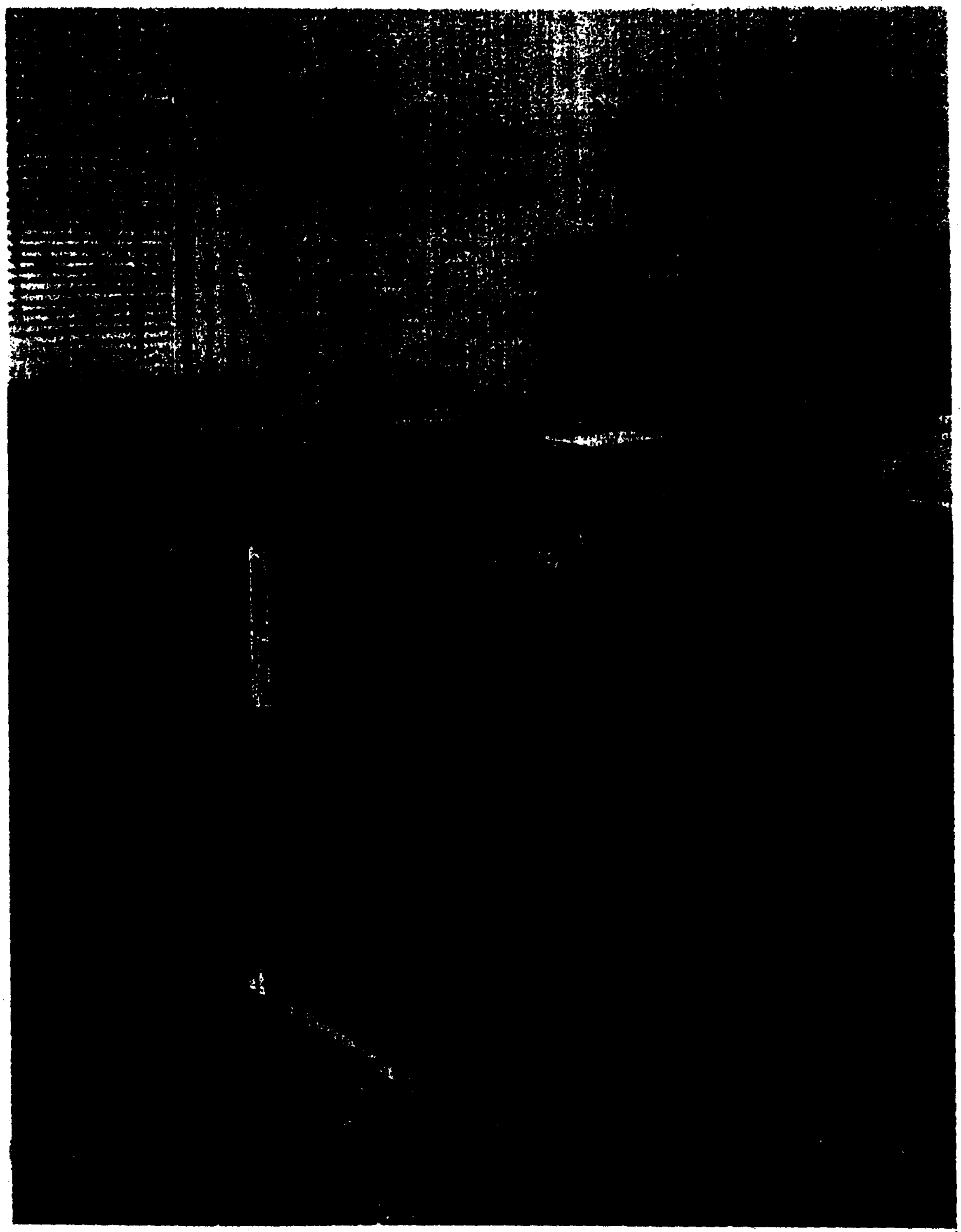

Figure 4-3
Temperature Control Cabinet, Exterior View

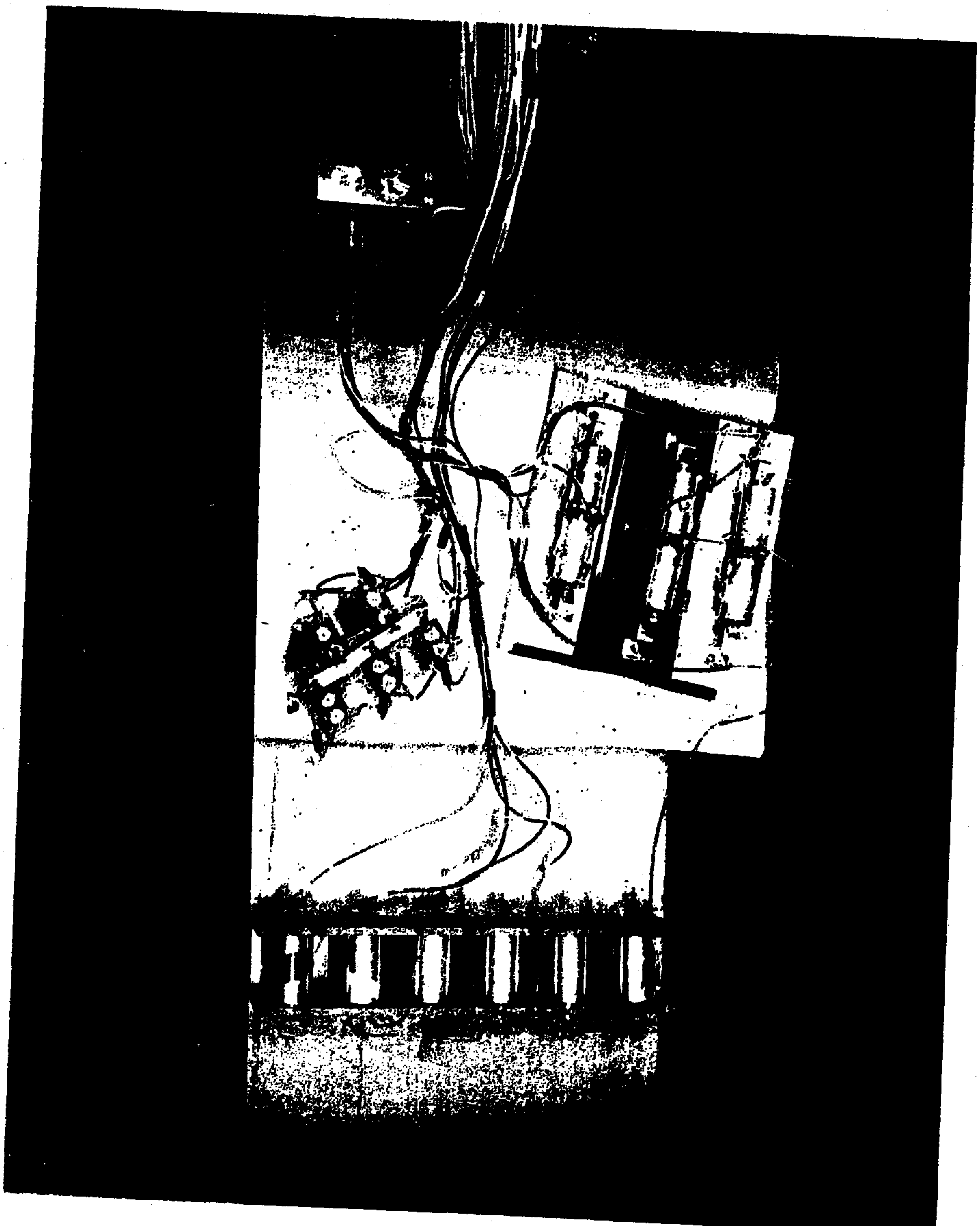

Figure 4-4
Temperature Control Cabinet, Interior View Showing Batteries Undergoing Life Test at 0°C

the ice cabinet and the testing area was regulated by a damper and a circulating fan.

The temperature was measured with a thermocouple and a bridge during the heat runs; a thermocouple and VTVM were used during the cold runs. To insure the most accurate reading, the junction of the thermocouple was affixed directly to one of the batteries being tested. The temperature in the testing area was regulated by a thermostat which controlled the position of the damper and the operation of the heater and fan. With this approach it was possible to hold the temperature to within $\pm 2^{\circ}C$ of the desired value. In hot runs the fan operated continuously whereas the heater was energized only when the temperature dropped below the desired value. In cold runs the ice cabinet was loaded to capacity with dry ice and natural convection carried cool air through the damper door (between the ice cabinet and fan) to the batteries. When this reduced the temperature in the test area below the desired value, the fan and the heater were turned on until the temperature rose to the proper value. Once temperature equilibrium was established the box was able to regulate continuously.

Leads were affixed to the battery terminals and brought out to a terminal board on the side of the box where the voltage readings were made. For most of the runs a recording voltmeter ran continuously giving a permanent record of the battery voltages.

b. Mountings. Special mountings to hold the batteries during the temperature runs were designed for each battery type with the following objectives in mind:

1) To provide a stable support
2) To insure permanent contact between the battery and the load
3) To avoid soldering the load resistors directly to the

batteries since the heat generated during such a process could be harmful to battery operation.

The objectives noted in (2) and (3) were obtained in a manner best suited to the particular battery type. The light weight RCA cells were inserted between a combination support-contact, which made contact around the entire circumference of the battery, and a spring-type contact which pressed firmly against the positive terminal. Leads were joined to these contacts. It was to these points that the load was soldered as were the leads which were brought outside the box for the purpose of recording voltages. For the heavier Mallory cells a stronger support of bakelite was utilized. Here too, a spring-type arm pressed against the positive terminal over a broad area. A metal bar with a critically located projection was bolted tightly on the bakelite mounting so that this projection was placed tightly on the negative terminal. Leads were brought from the metal bar and the spring connection to the load. The contacts to the Yardney batteries were considerably simpler. The batteries were placed side by side for support and a series of links made one common connection to the negative terminals. In this case the load resistors had special terminals joined to them. These were bolted to the positive terminals while the other end was soldered to a lead paralleling the connecting links to prevent soldering directly to the terminals.

The Voltabloc cells were also placed side by side for support (insulated from each other) and were loaded with resistors having terminals just as was done by the Yardney batteries. All the Gould Button and Deac cells were mounted on one bakelite stand with spring clips on both terminals for the button cells. A similar type of arrangement was used for cylindrical cells which had a clip for one of its terminals. Here too the resistors had terminals and were bolted to the back of the above-mentioned spring clips.

Note that the load resistors were placed in the same environment as the batteries so that the entire system experienced identical conditions. Before starting a life test the system was allowed to reach the desired temperature and then the load resistors were connected and the load voltages recorded. Resistance values were also measured when the resistors were at the particular temperature of the test at the conclusion of the run.

3. Factors Considered

a. Load Resistors. Choice of the proper load resistor presented a conflict of interests. The more desirable choice would have been to discharge the batteries in approximately one month or about the same time that would be required of them in actual use. This was impractical because the large number of tests required over a wide range of temperatures did not permit more than an average of 100 hours per test. The value of the load resistance was calculated on the basis of the nominal manufacturer's rating.

At the higher temperatures the internal resistance is at least as small as the internal resistance at room temperature so that an accelerated test with its higher current drain would still allow the cell to deliver most of its charge before the terminal voltage reached the minimum tolerable value.

At the lower temperatures, however, the internal resistance of some of the batteries is increased. This means that the larger the current drain the more quickly the terminal voltage will fall with less chance that the full capacity of the cell will be delivered. As a result the watt-hour figures given below for low temperature runs may be much lower than that obtainable for the lower current drains which would occur in the actual intended use. In other words, the low temperature data are pessimistic.

b. Minimum Tolerable (End Point) Voltage. This was chosen according to the particular battery type.

The Yardney/Silvercell voltage-versus-time characteristic consists of two plateaus with the voltage at the last of these being a function of temperature. For these cells, then, the end point voltage was that at which the value of the last plateau diminished sharply from its average value.

Plateaus are not so evident in the case of either the RCA or the Mallory battery. The end point for these two types, then, is that at which the voltage begins its final sudden drop. This voltage occurs at different values depending upon the temperature. A number of different end points were considered for these two cell types.

c. Watt-Hours Determination. This quantity was computed on an hourly basis by considering the hourly voltage reading as the average voltage for that time period. This gives a more accurate watt-hour total than if just the end voltage were utilized.

A chemical scale was available for determining the weight of the various types of cells so that watt-hours per pound could be computed. These weights are as follows:

RCA	= 30 grams
Yardney	= 124 grams
Mallory (without paper cover)	= 164 grams
Voltabloc V04	= 170 grams
Gould Button Type 32 B	= 14.6 grams
Type 23 B	= 5.9 grams
Deac Type 450 D	= 22.6 grams
Deac Type 220 D	= 12.5 grams
Deac Type 150 DK	= 9.6 grams
Deac Type 120 DK	= 8.8 grams
Deac Type 90 DK	= 7.4 grams
Deac Type 60 DK	= 3.5 grams

4. Experimental Procedure

a. Readings of load voltage were not taken until the cells reached the equilibrium temperature. Resistance values were also read under these conditions.

b. Voltages were read at least once every hour and more often where rapid changes occurred during the working day. A recording voltmeter equipped to read 24 channels recorded the voltages once an hour day and night.

5. Test Results

a. Room Temperature Test Results. The room temperature data are used as the basis of comparison in the presentation of the test results because present indications are that the average vehicle temperature will be in this vicinity.

The voltage-versus-time characteristics are vital factors in determining the suitability of a particular battery for performing a certain task under specialized environmental conditions. Figs. 4-5, 4-6, 4-7, and 4-8 illustrate the best performance of the cells for the entire temperature range studied. (See also Table 4-4.) The RCA and the Mallory batteries are characterized by operation at an almost constant level for most of the discharge. Almost immediately upon leaving this level both battery types dropped to voltages below the useful-power level. The Yardney cell differs radically from the other types in that its discharge is characterized by two plateaus, the first occurring at about 1.80 volts and the second and longer at about 1.50 volts. Upon leaving the last plateau the fall-off is quite rapid. The choice of end voltages therefore was automatic. For the RCA it was no more than 1.00 volt, for the Mallory no more than 1.10 volts and for the Yardney no more or less than 1.50 volts. Choice of end voltages as low as 0.80 volt for the RCA and 1.00 volt for the Mallory would improve the watt-hour figures by less than two percent.

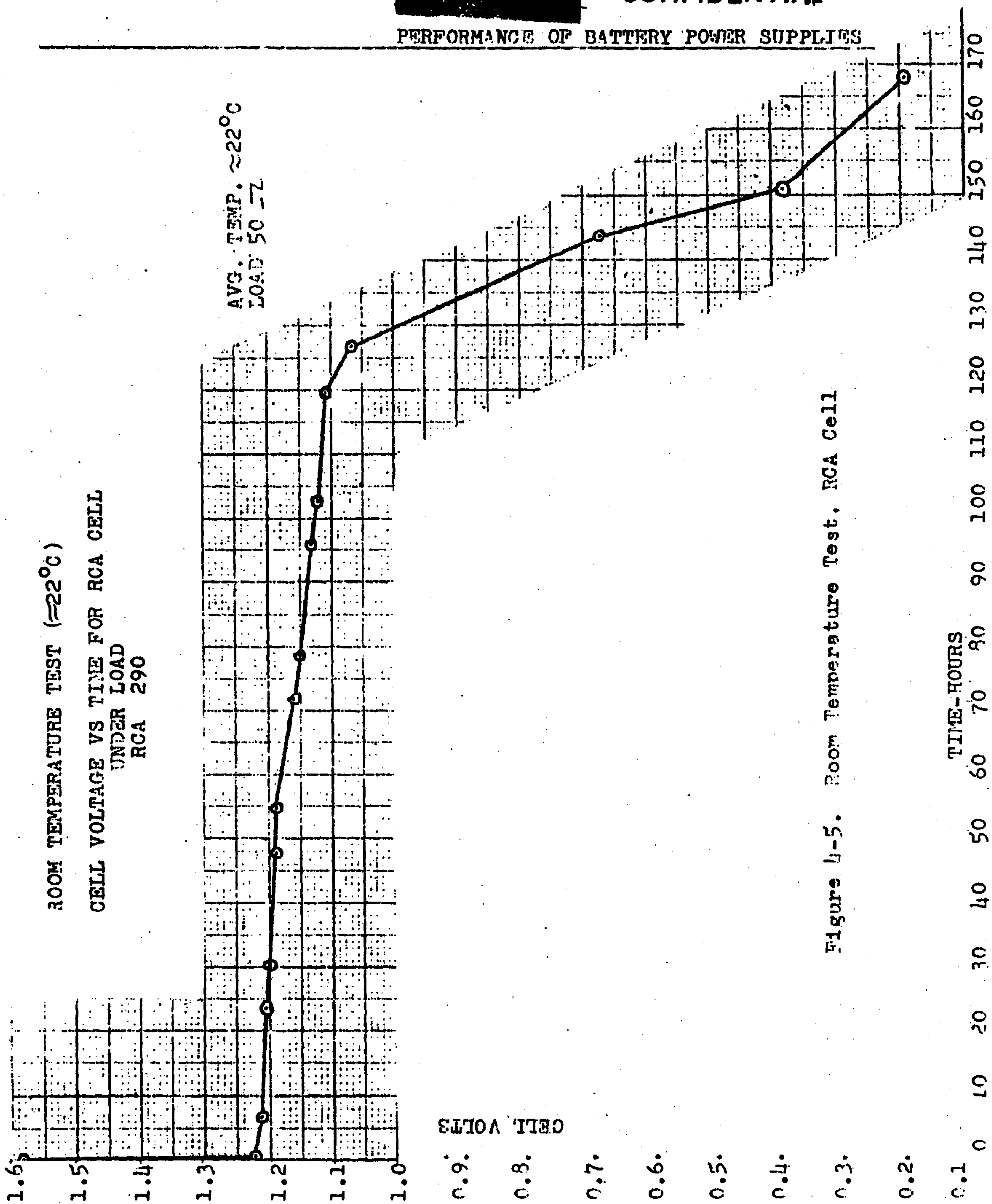

Figure 4-5. Room Temperature Test, RCA Cell

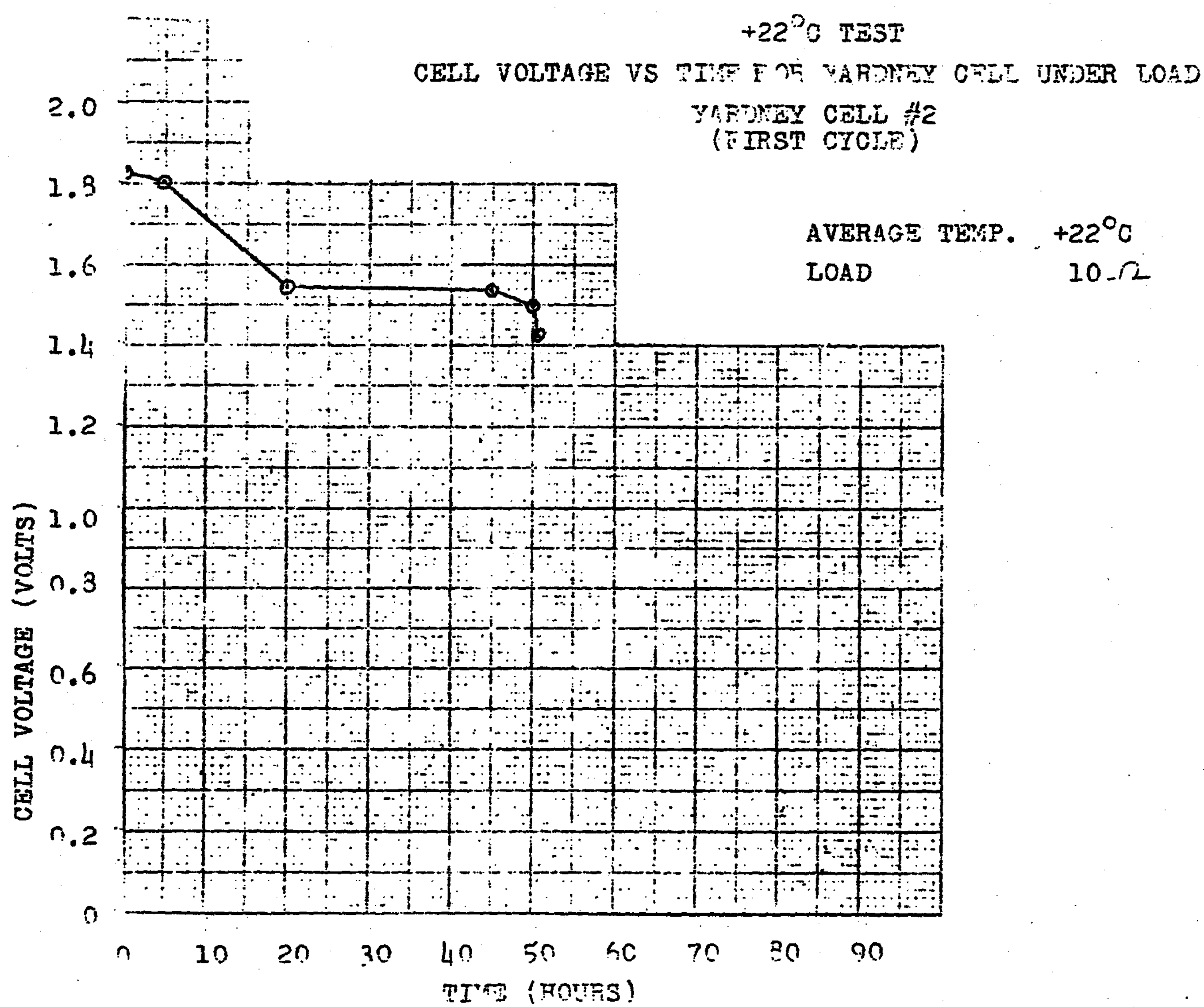

Figure 4-6. Room Temperature Test, Yardney Cell No. 2 (First Cycle)

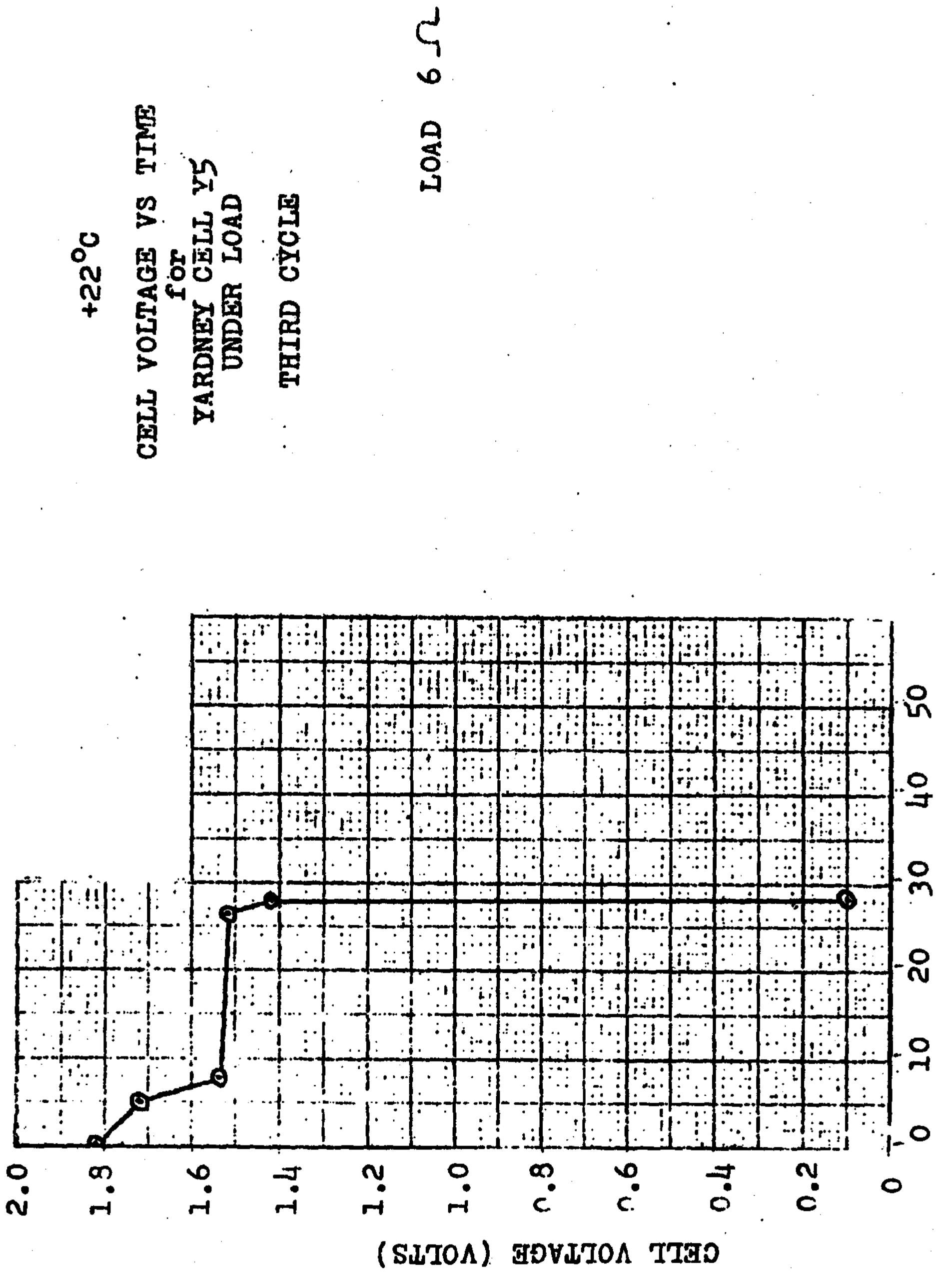

Figure 4-7. Room Temperature Test, Yardney Cell No. 2 (Third Cycle)

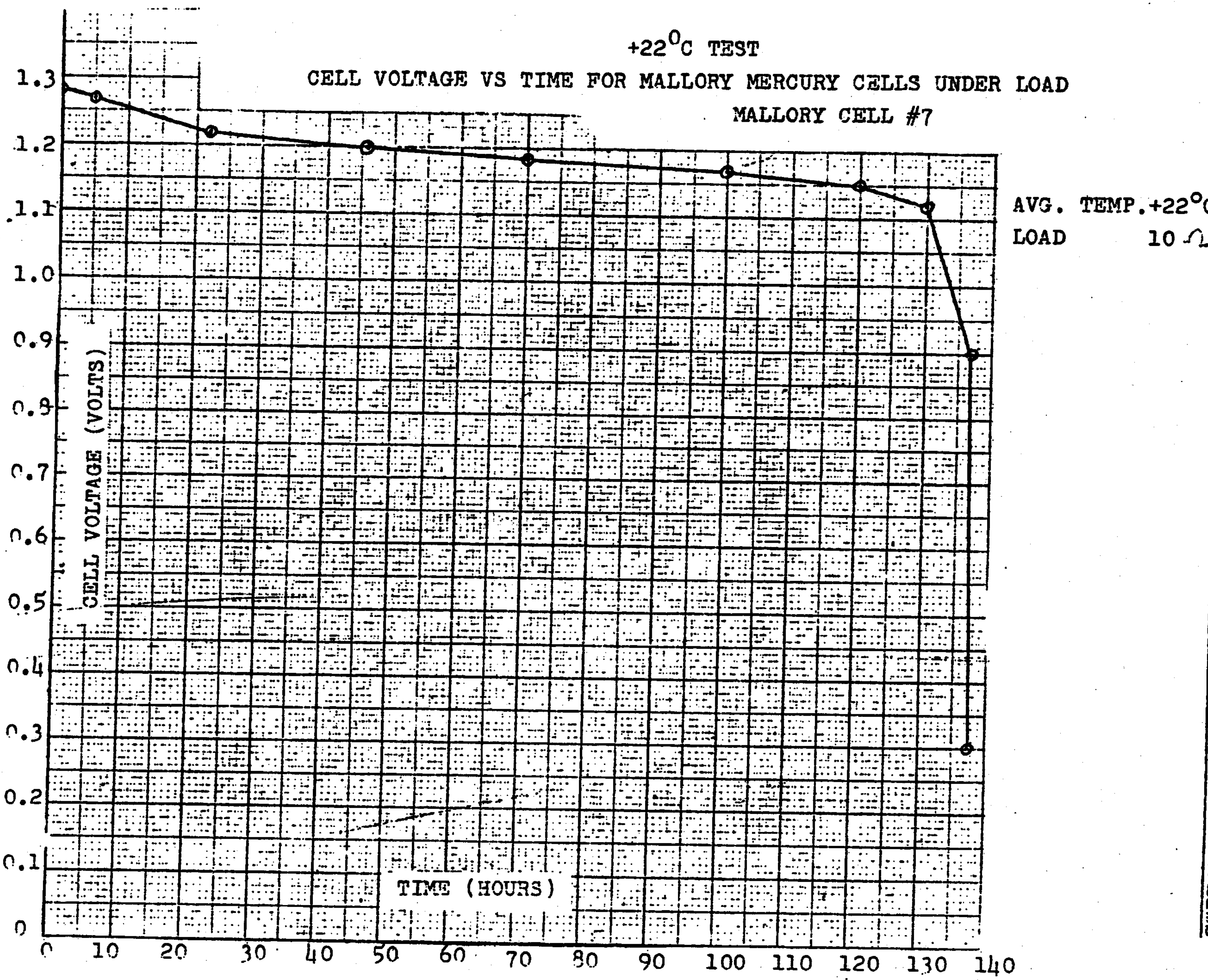

Figure 4.8. Room Temperature Test. Mallory Mercury Cell No. 7

TABLE 4-4

Results at +22°C

CELL IDENTITY	END VOLTAGE	WATT-HOURS	WATT-HOURS PER POUND
RCA BATTERY (50-OHM LOAD)			
243	1.00	4.05	61.1
290	1.00	4.00	60.5
243	0.90	4.08	61.9
290	0.80	4.07	61.8
MALLORY BATTERY (10-OHM LOAD)			
7	1.10	18.7	51.5
8	1.10	17.0	47.0
7	1.00	19.0	52.5
8	1.00	17.2	47.6
YARDNEY BATTERY (10-OHM LOAD) (FIRST CYCLE)			
2	1.50	13.2	48.3
3	1.50	13.8	50.5
5	1.50	13.4	49.0
6	1.50	10.9	38.8
	(6-OHM LOAD)		
3	1.50	11.3	41.3
5	1.50	11.2	40.9

The encouraging results given above for watt-hours per pound and discharge performance are somewhat dimmed for the RCA and Yardney cells by the physical effects of the discharge process. Near the end of the load test it was observed that cracks appeared in the case of the RCA cell indicating that the case itself was being consumed in a chemical reaction with the ingredients inside the cell. The result was the formation of gray furry projections along various portions of the case. These could not be tolerated in actual operation as they could easily cause shorts between cells.

The Yardney cells upon being charged in the forming process and also upon discharge deposit a blue-gray powder from the zinc or negative plates. Should there be a violent movement of the battery it would be possible for the electrolyte to transfer this powder over the jacket which separates the positive and negative plates and in doing so short the plates.

b. Results of the 40°C Temperature Test. The voltage characteristics are given in Figures 4-9, 4-10, and 4-11. (See also Table 4-5.) The disappointing performance watt-hourwise of the RCA and Yardney cells will be covered below in the summary of temperature tests.

Both the RCA and the Mallory cells operated at higher load voltages than they did at +22°C. This is partly the result of the lower internal resistance at the higher temperature for the same current drain. The Mallory cell showed little change from the +22°C values in watt-hours because the initial increase in voltage output was offset by a pronounced tail-off long before the sudden drop occurred at the 1.10 volt end point. All the RCA cells suffered the same severe undesirable alteration in the discharge curve. The voltage output would remain almost constant at an average value of 1.22 volts until it would rise suddenly and then plunge well below 1.00 volt. The watt-hour total

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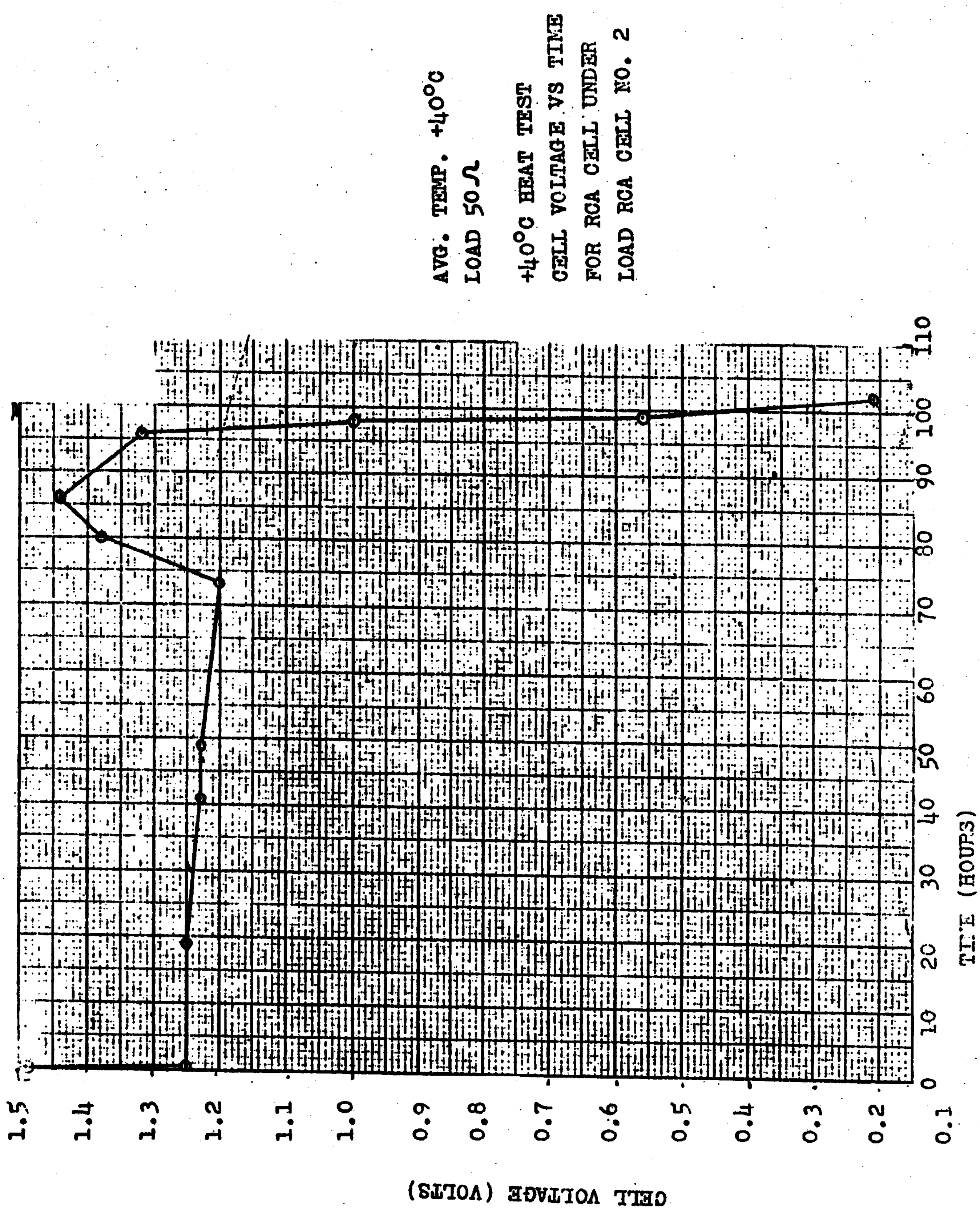

Figure 4-9 +40°C Test - RCA Cell No. 2

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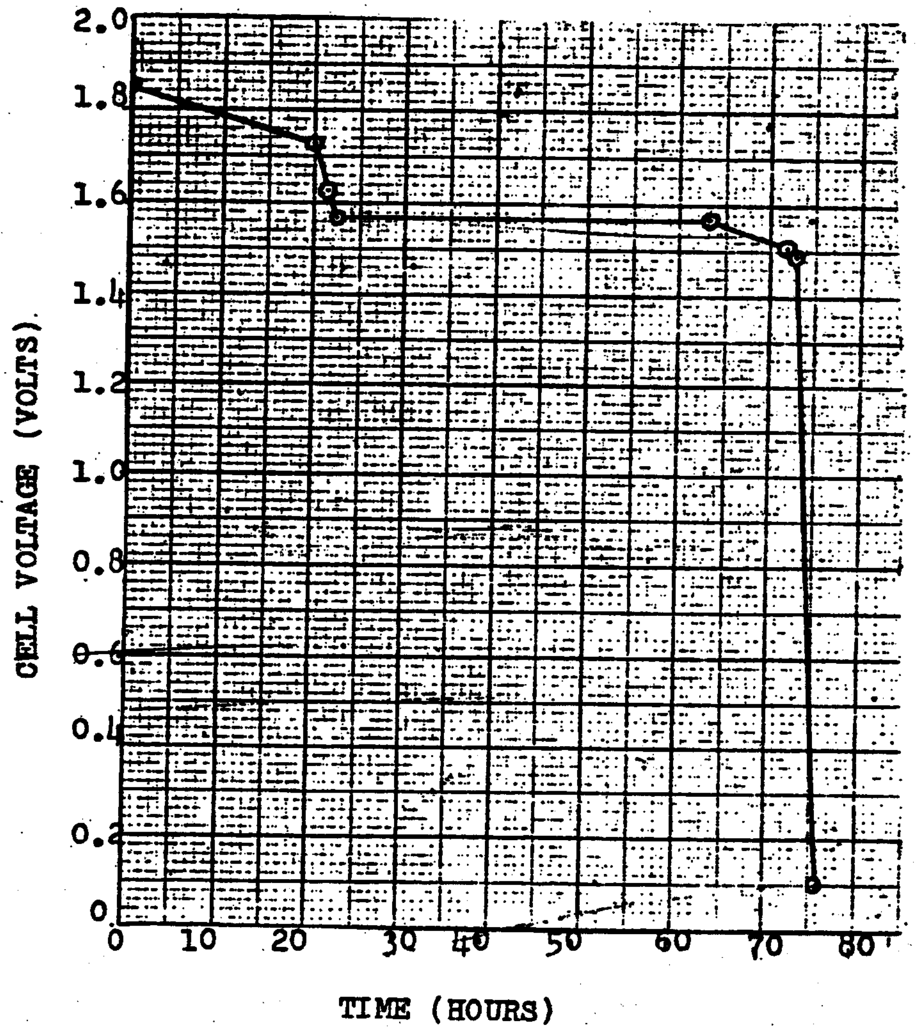

+40°C HEAT TEST

CELL VOLTAGE VS TIME
FOR YARDNEY CELL UNDER
LOAD

YARDNEY CELL 8
FIRST CYCLE

AVG. TEMP. +40°C
LOAD 22 Ω

Figure 4-10. +40°C test, Yardnsy Cell No. 8 (First Cycle)

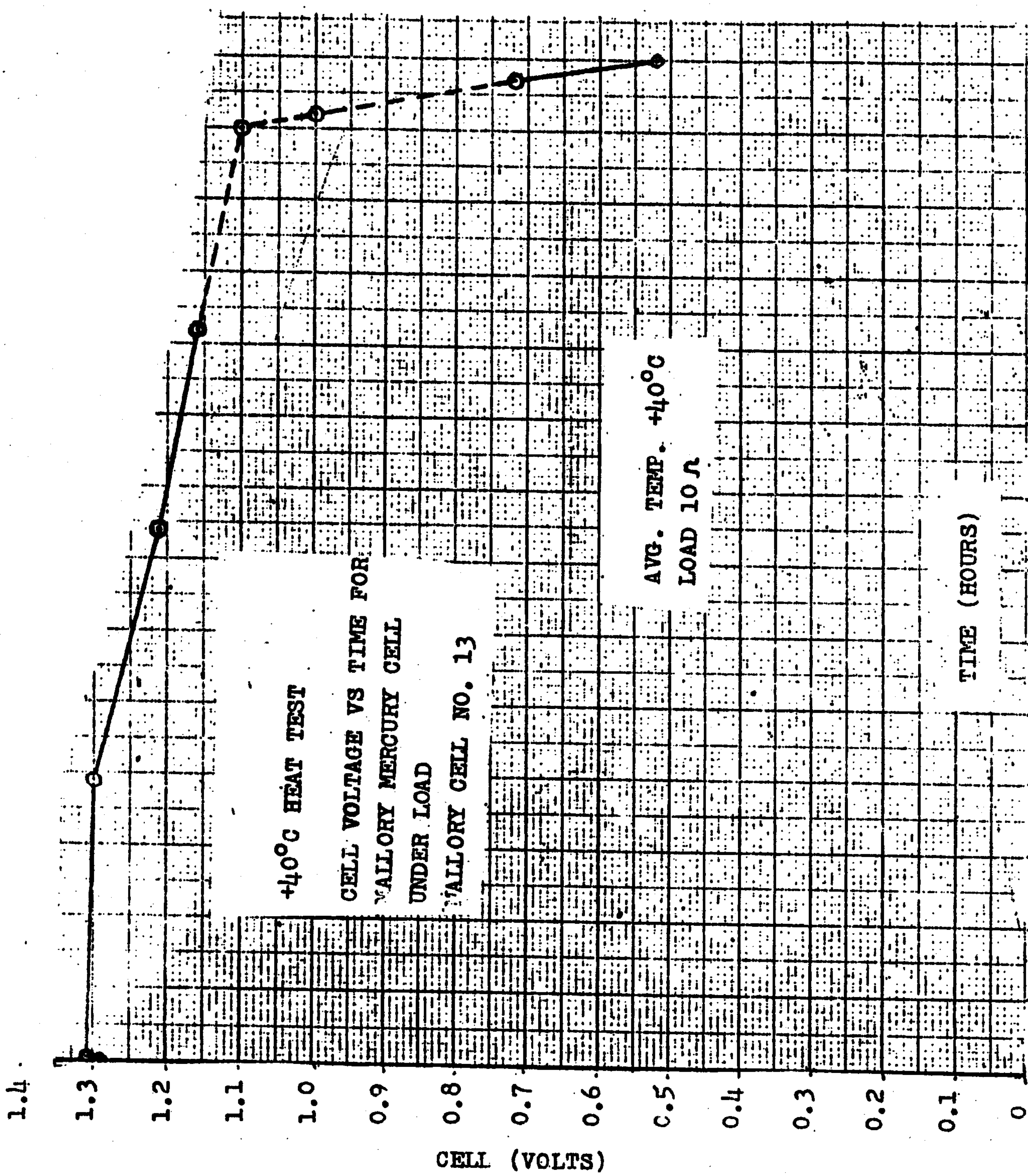

Figure 4-11. +40°C Test, Mallory Cell No. 16.

TABLE 4-5
RESULTS AT +40°C

CELL IDENTITY	END VOLTAGE	WATT-HOURS	WATT-HOURS PER POUND
RCA BATTERY (50-OHM LOAD)			
1	1.00	2.97	44.9
2	1.00	3.33	50.3
3	1.00	3.56	53.7
4	1.00	3.32	50.2
5	1.00	3.17	47.8
6	1.00	3.41	51.5
MALLORY BATTERY (10-OHM LOAD)			
11	1.10	18.4	50.8
12	1.10	18.6	51.4
13	1.10	19.1	52.7
14	1.10	18.3	50.5
YARDNEY BATTERY (22-OHM LOAD) (FIRST CYCLE)			
7	1.50	10.2	37.0
8	1.50	9.19	33.6
9	1.50	9.96	36.5
10	1.50	9.20	33.7
11	1.50	8.00	29.2
12	1.50	8.93	32.7

suffered because the useful discharge period was only 75 percent as long as at +22°C.

The Yardney cell was loaded with a 22-ohm resistor in this test whereas a 10-ohm load resistor was used at +22°C. The drain at +40°C was less than half that at +22°C. One would then expect that this would mean an increase in watt-hours, but this was not the case. Although the period of discharge was lengthened, performance at +40°C was not comparable to that obtained at room temperature.

A note on the +40°C heat run on the Mallory cells under load. After the 102nd hour no readings were taken of the Mallory cell voltages until the 137th hour. During this interval all of the cell voltages dropped from about 1.16 volts to appreciably less than 1.0 volt. In order to obtain a reasonable approximation to the total watt-hours the following procedure was used: From previous tests, notably the +22°C run, it was observed that the voltages of these cells took approximately 10 hours to fall to their final low voltages after reaching about 1.1 volts. On this basis it was decided to give all the voltage-versus-time curves the same slope between the end point and 137 hours. This section, shown dotted in Figure 4-11, has approximately the same slope as that found during the +22°C test for the same region of voltages. From these curves total watt-hours were determined.

c. Results of the +60° Temperature Test. At +60°C the phenomenon of increased initial load voltage over that at room temperature is even more pronounced than at 40°C. (See Figures 4-12, 4-13, and 4-14 and Table 4-6.) Here again the Mallory cell failed to improve its watt-hour figures because of a more pronounced tail-off and quicker drop below the end voltage (1.10 volts). Performance of the RCA cell at +60°C was much improved from a watt-hours and discharge characteristic standpoint. The Yardney cells produced almost identical results to those at +40°C.

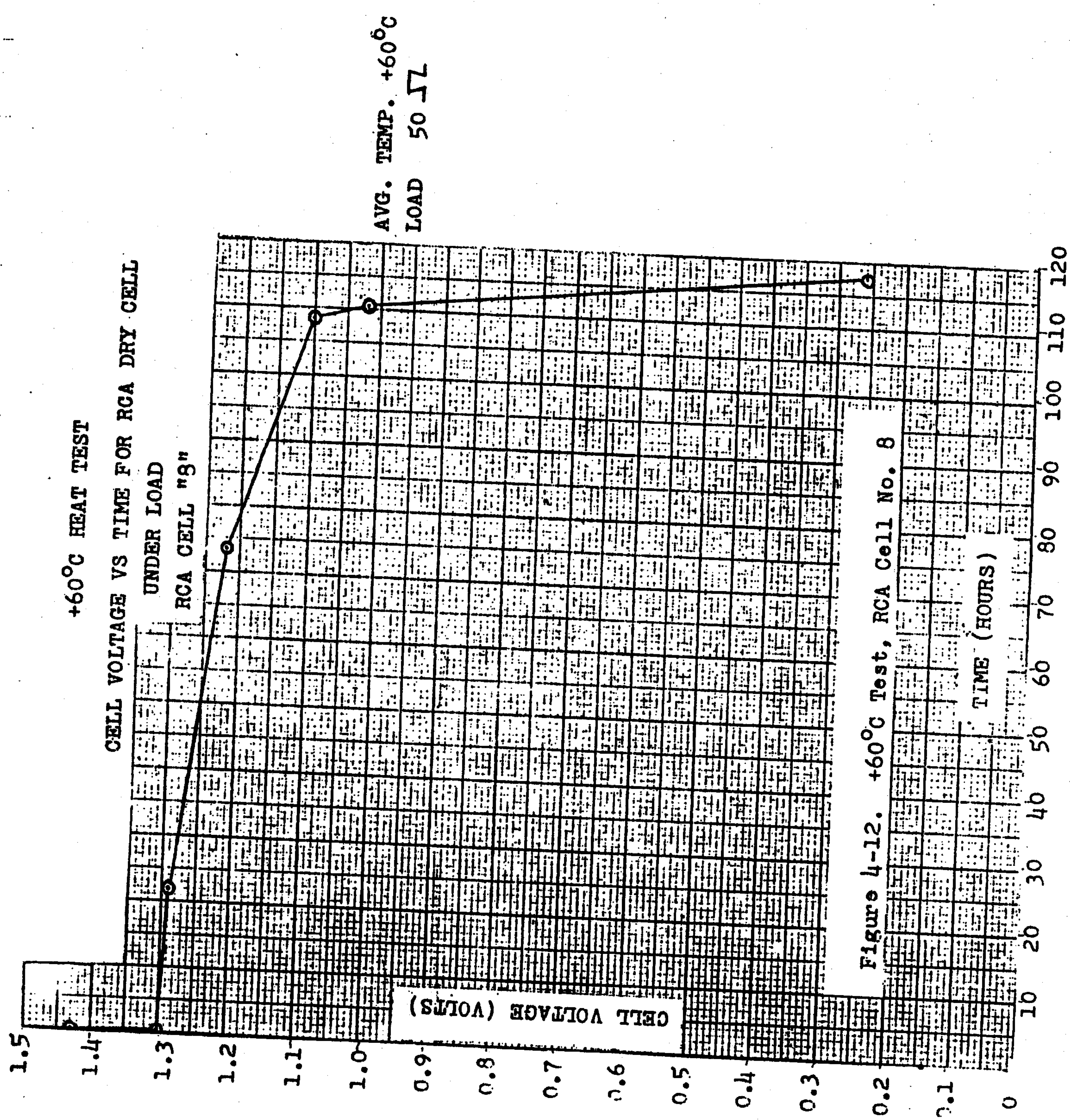

Figure 4-12. +60°C Test, RCA Cell No. 8

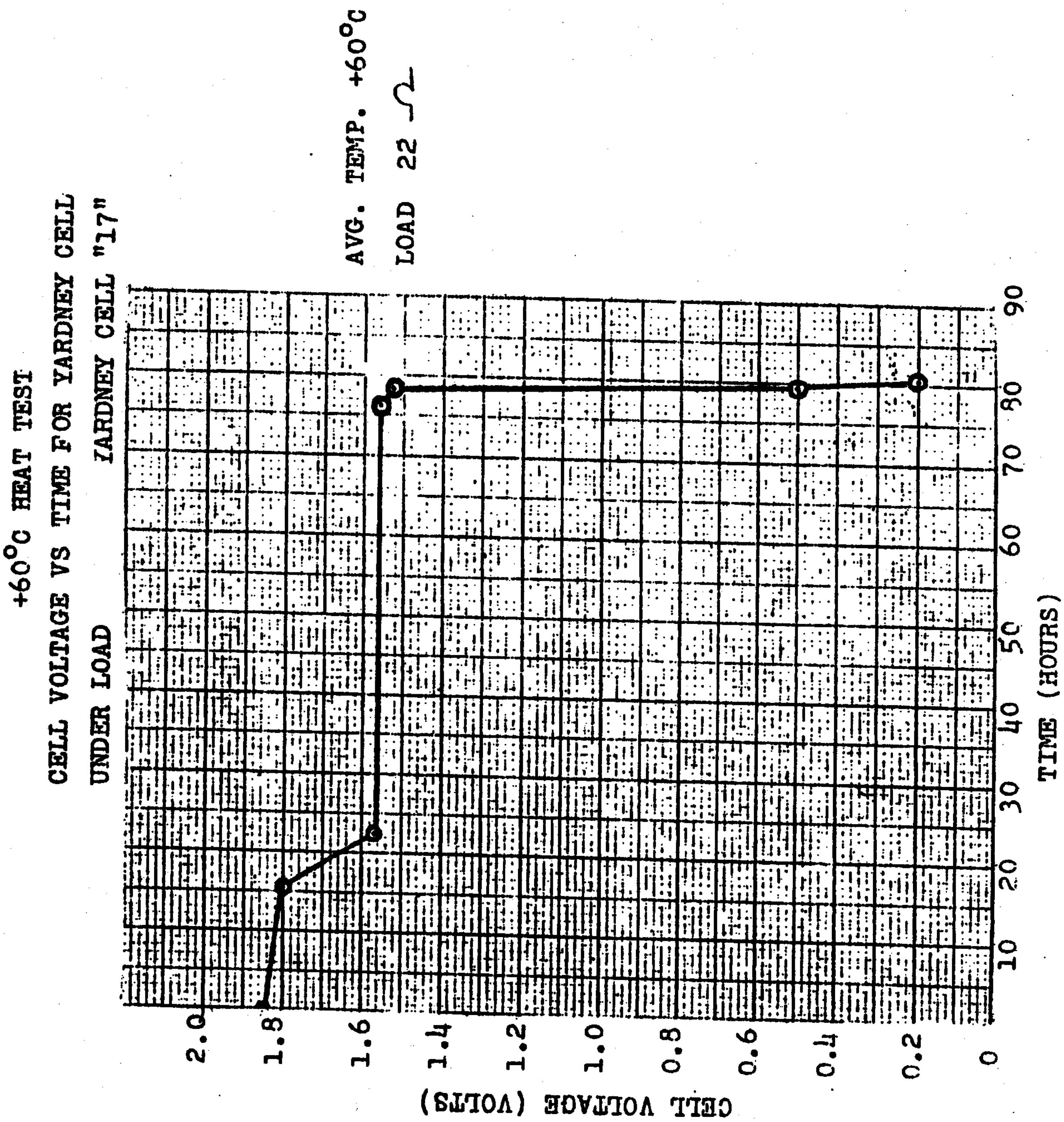

Figure 4-13. +60°C Test, Yardney Cell No. 17

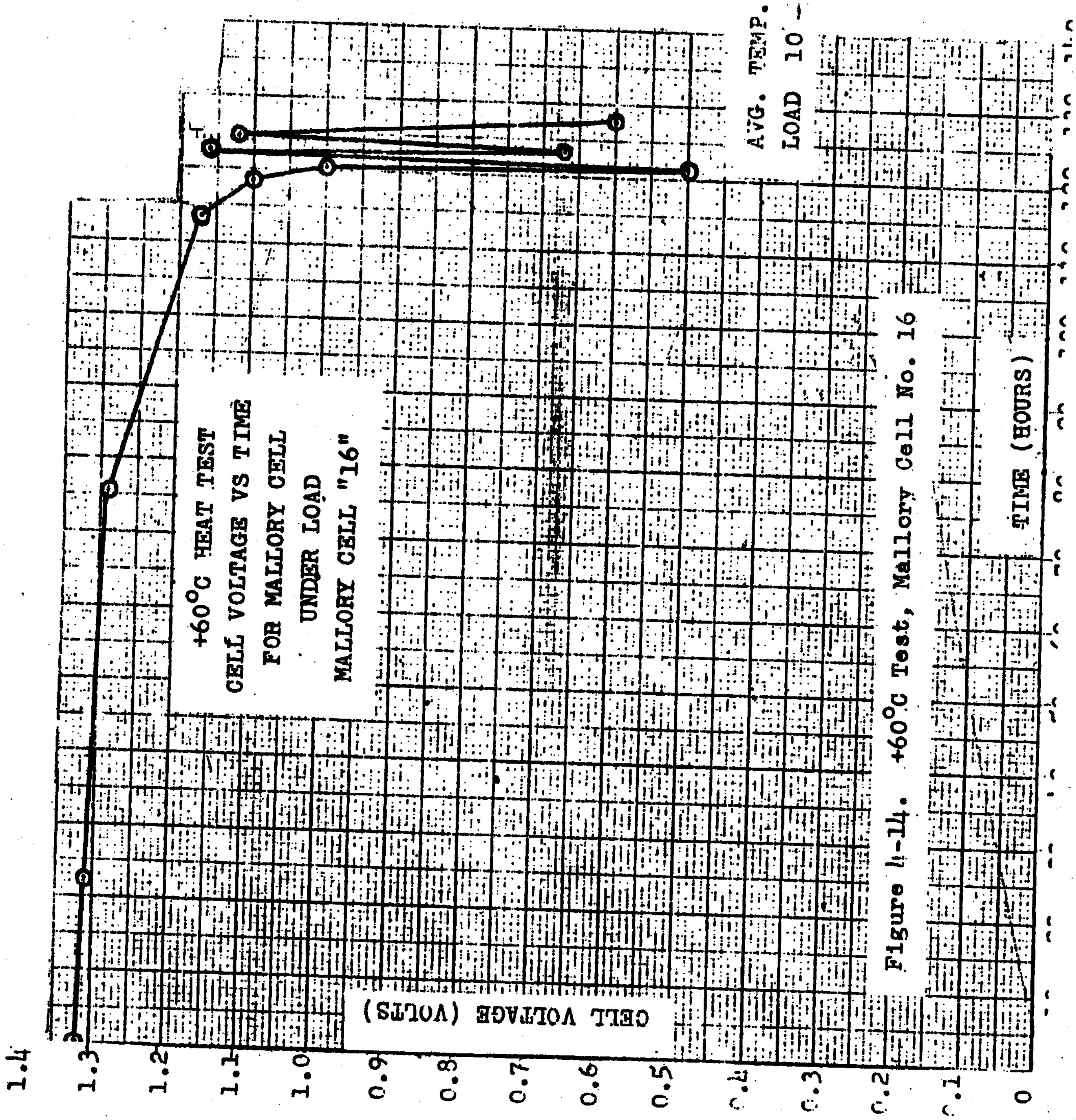

Figure 4-14. +60°C Test, Mallory Cell No. 16

TABLE 4-6

RESULTS AT +60°C

CELL IDENTITY	END VOLTAGE	WATT-HOURS	WATT-HOURS PER POUND
RCA BATTERY (50-OHM LOAD)			
7	1.00	3.45	52.1
8	1.00	3.72	56.1
9	1.00	4.04	61.0
10	1.00	3.84	58.0
11	1.00	3.66	55.3
12	1.00	3.49	52.8
MALLORY BATTERY (10-OHM LOAD)			
15	1.10	17.9	49.5
16	1.10	18.4	50.9
17	1.10	17.6	48.5
18	1.10	18.9	52.1
19	1.10	18.9	52.1
20	1.10	17.3	47.8
YARDNEY BATTERY (22-OHM LOAD) (FIRST CYCLE)			
13	1.50	8.70	31.8
14	1.50	9.79	35.7
15	1.50	9.08	33.1
16	1.50	10.42	38.0
17	1.50	9.61	35.1
18	1.50	8.33	30.4

With one exception the physical effects on all the cells were the same as reported for the 22°C run. At +60°C the wax seal on some of the RCA cells showed signs of blistering. This effect may have provided a leakage path for some of the moisture. Work is still being carried out to determine the most suitable seal for a particular temperature range.

All previous indications were that battery operation would be more seriously affected by the lower temperatures so these were taken in 10° intervals.

TABLE 4-7
Results at -20°C

RCA BATTERY (50-OHM LOAD)

CELL IDENTITY	END VOLTAGE	WATT-HOURS	WATT-HOURS PER POUND
D	1.0	0.763	11.5
K	1.0	0.618	9.35
D	0.92	0.892	13.1
K	0.92	0.699	10.6
YARDNEY BATTERY (10-OHM LOAD) (SECOND CYCLE)			
2	1.20	2.74	10.0
3	1.24	4.30	15.7
4	1.21	5.70	20.8
5	1.21	6.62	24.2
6	1.22	5.26	19.2

d. Results of the -20°C Test. The -20°C test was the lowest temperature test performed. No Mallory cells were tested at this temperature since the cells were found to fail at -10°C. The Yardney and the RCA cells suffered badly at -20°C. (See Figures 4-15 and 4-16 and Table 4-7.) The discharge characteristic of the Yardney cell would be totally unsuitable at this temperature as it does not maintain a constant voltage for a reasonable time.

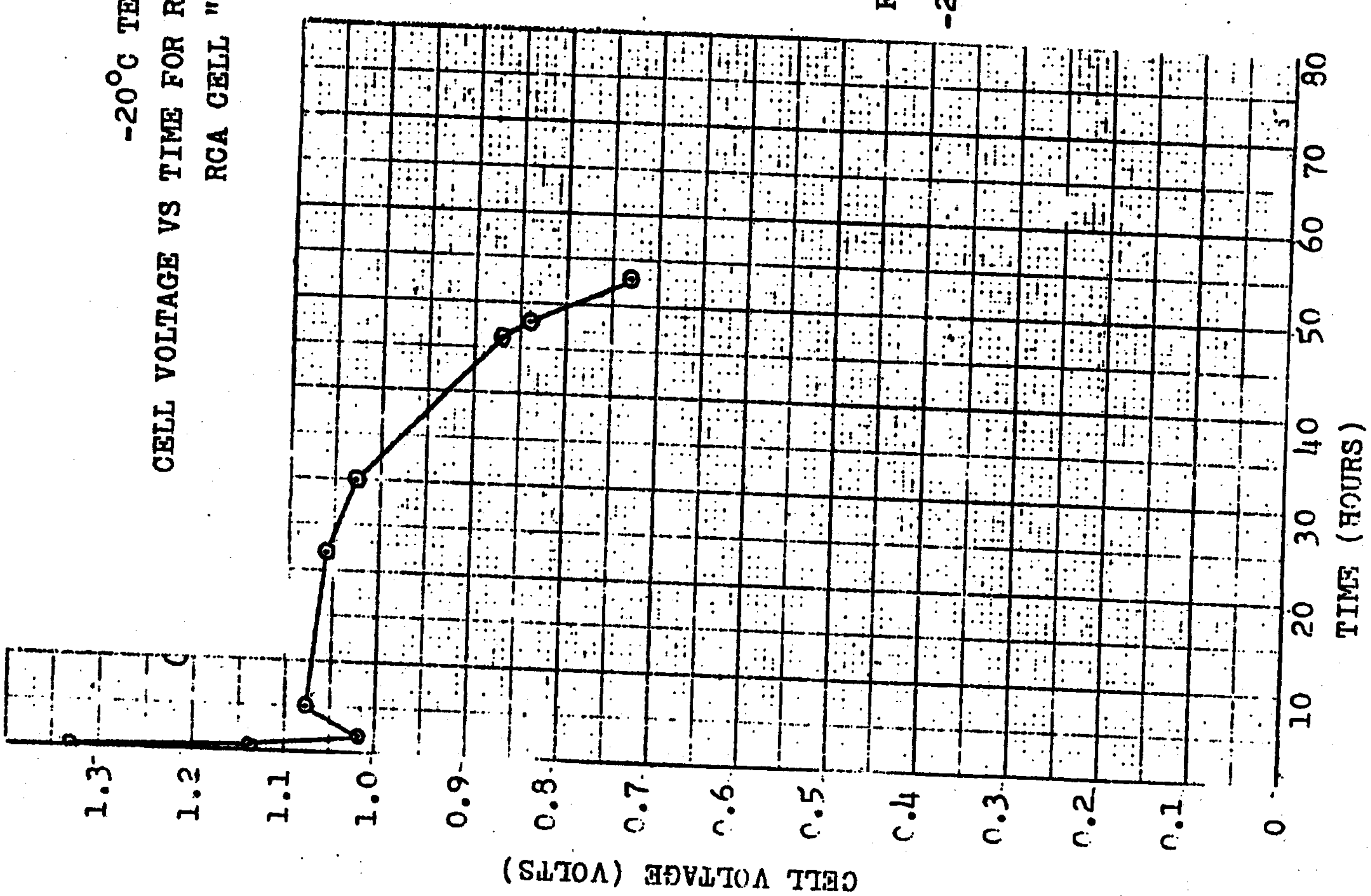

Figure 4-15.
-20°C Test, RCA Cell "D"

-20°C TEST
CELL VOLTAGE VS TIME FOR YARDNEY CELL UNDER LOAD
SECOND CYCLE

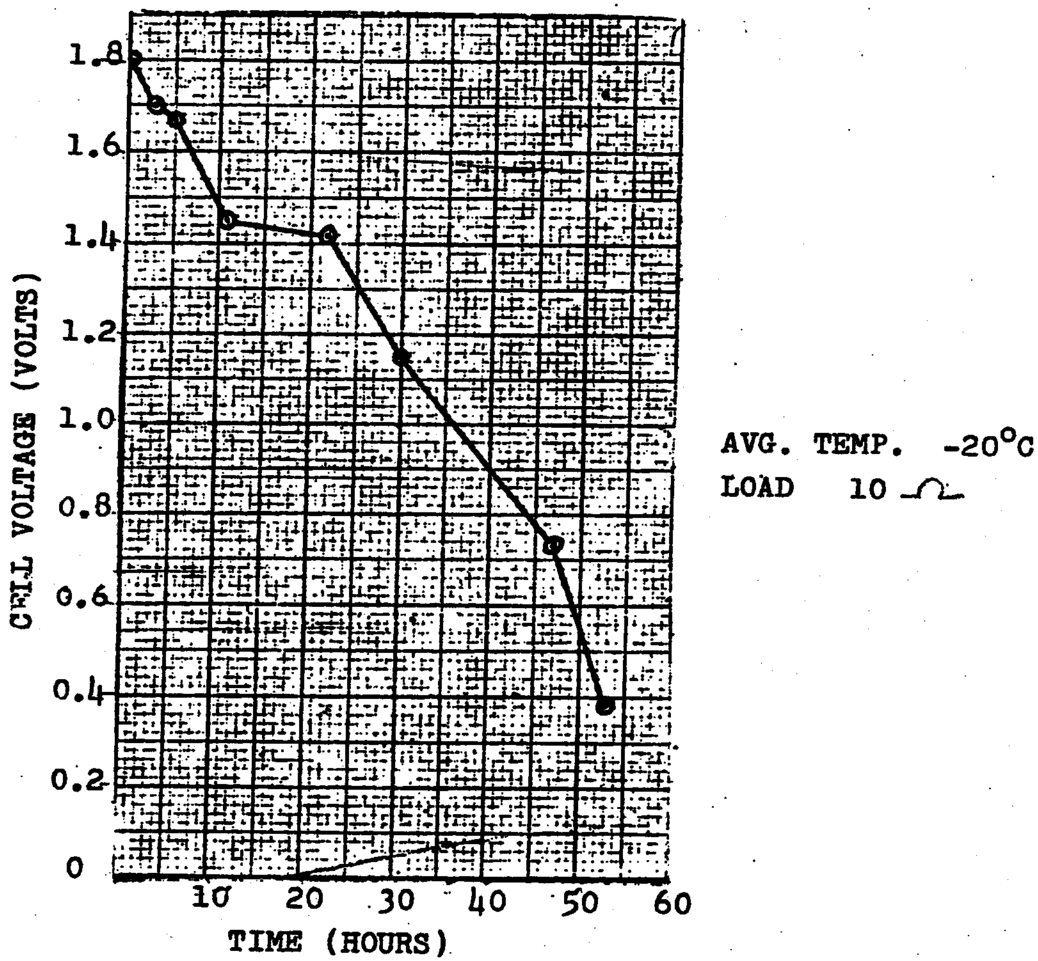

Figure 4-16. -20°C Test, Yardney Cell (Second Cycle)

The RCA cells also were characterized by a constantly changing voltage which never maintains itself over 1.10 volts. The failure of these cells to operate successfully is finally borne out by their low watt-hour per pound figures.

TABLE 4-8

Results at -10°C

CELL IDENTITY	END VOLTAGE	WATT-HOURS	WATT-HOURS PER POUND
RCA BATTERY (50-OHM LOAD)			
A	1.00	1.43	21.6
B	1.00	1.34	20.3
G	1.00	1.34	20.3
H	1.00	1.79	27.0
A	0.90	1.77	26.7
H	0.90	1.73	26.2
B	0.80	1.62	24.5
G	0.80	1.85	29.0
H	0.80	2.09	31.6
MALLORY BATTERY (10-OHM LOAD)			
5	0.80	0.33	0.91
6	0.80	0.25	0.69
YARDNEY BATTERY (39-OHM LOAD) (FIRST CYCLE)			
1	1.50	7.8	28.5
4	1.50	7.8	28.5

e. Results of the -10°C Test. Results of the -10°C test are shown in Figures 4-17, 4-18 and 4-19 and Table 4-8. At -10°C the failure of the Mallory cell to withstand low temperatures is clearly demonstrated. Performance of the RCA cell is considerably improved although its voltage is never above 1.20 volts. In this case the tail-off is not as sharp as it was at +22°C so that choice of end voltages lower than 1.00 volt have a considerable effect on the watt-hours per pound

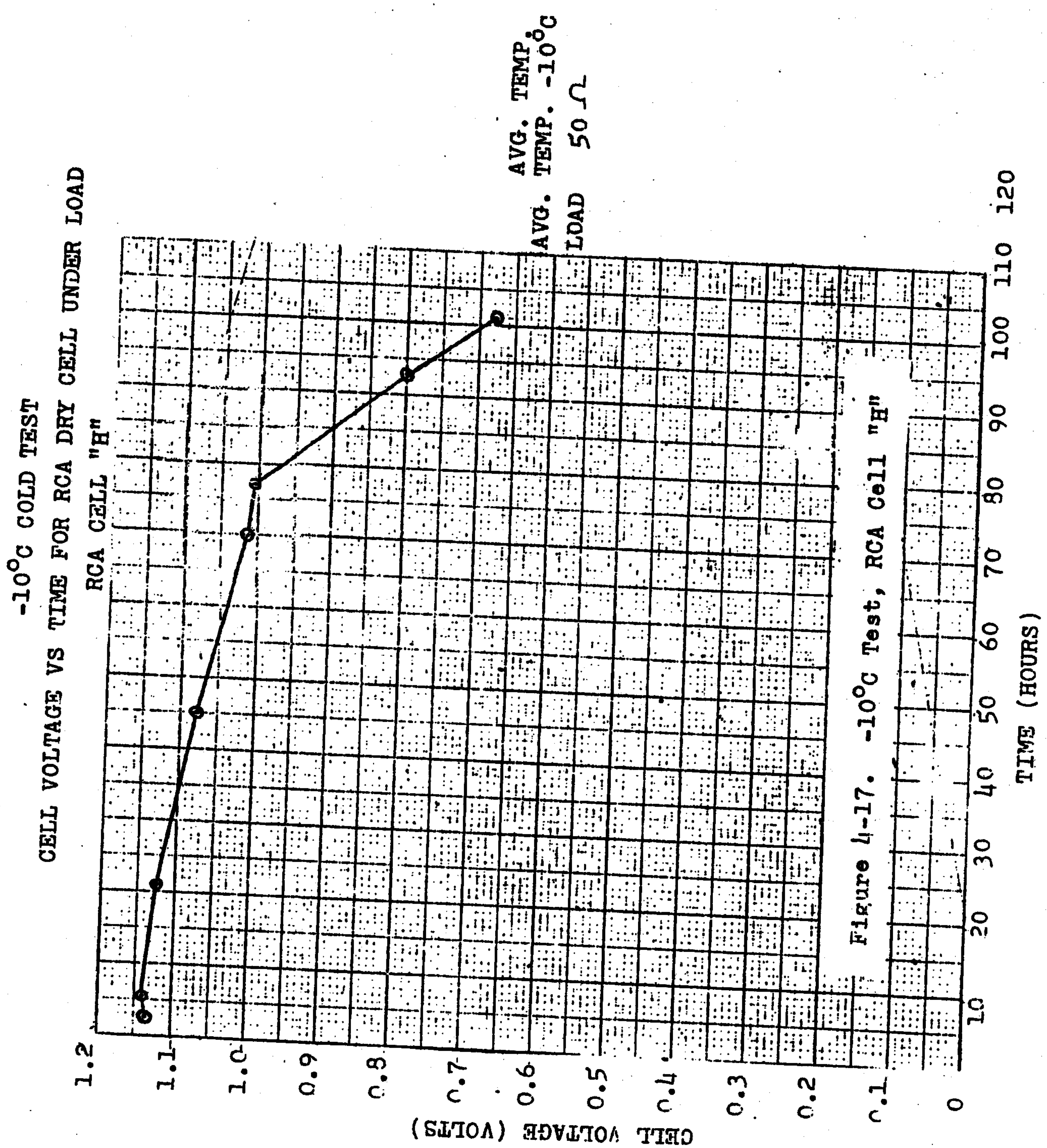

Figure 4-17. -10°C Test, RCA Cell "H"

-10°C COLD TEST
CELL VOLTAGE VS TIME FOR YARDNEY CELL UNDER LOAD
YARDNEY CELL #1
FIRST CYCLE

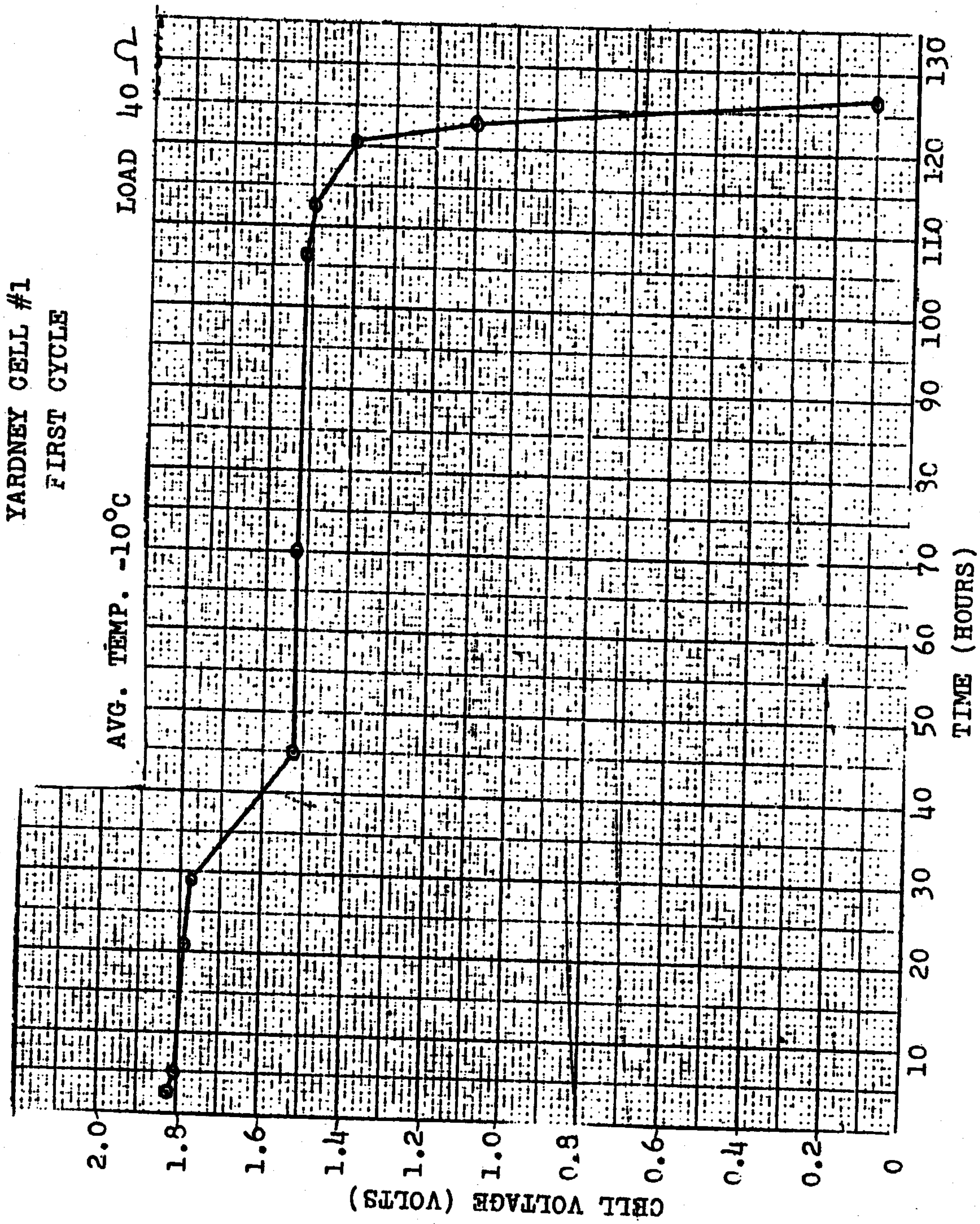

Figure 4-18. -10°C Test, Yardney Cell No. 1 (First Cycle)

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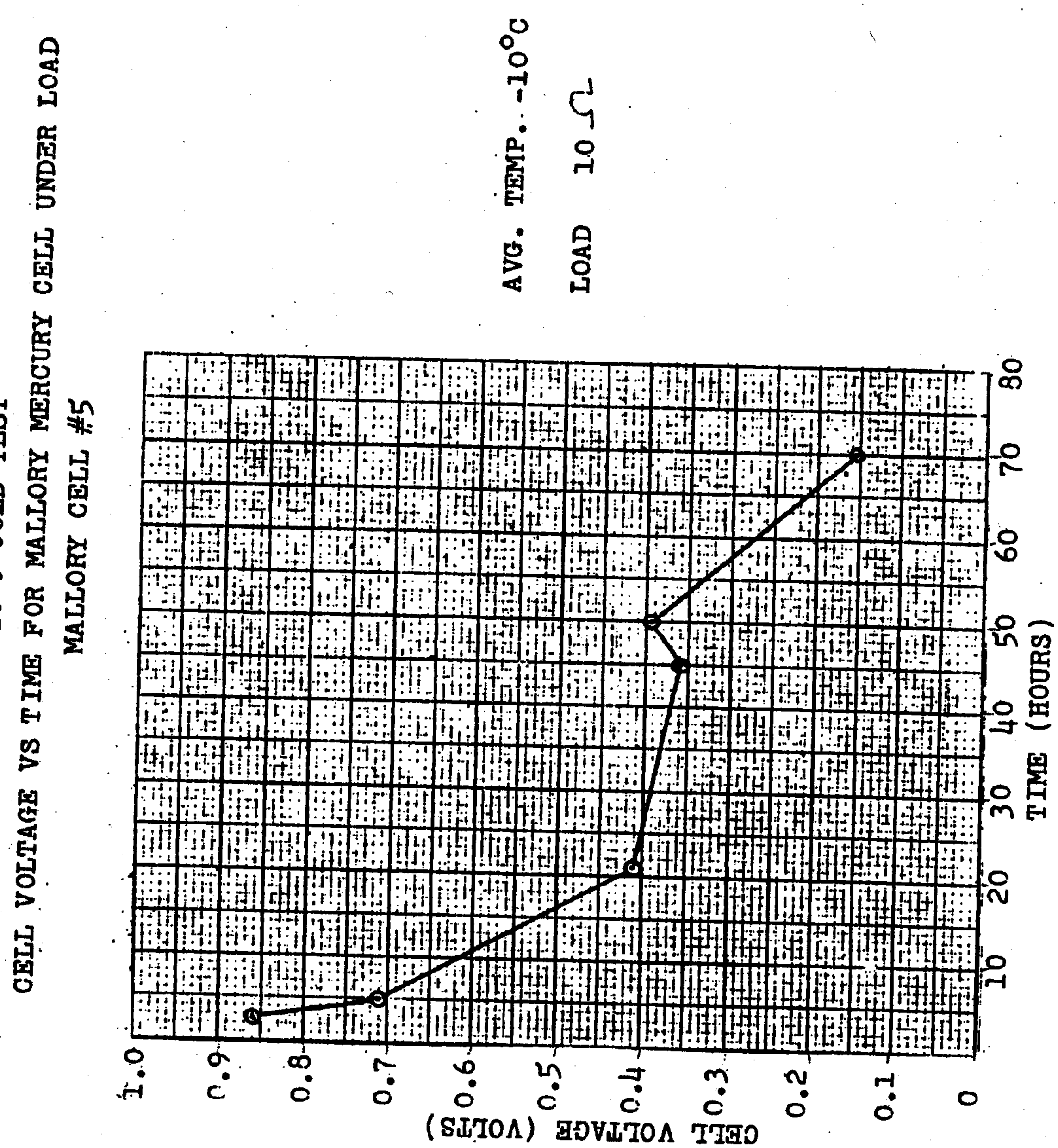

Figure 4-19. -10°C Test, Mallory Cell No. 5

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The load was such that the Yardney cell required only one quarter the current that it did at -20°C and half as much as at +22°C. This accounts for the much longer discharge time at -10°C than at +22°C. The fact that this test did not yield the watt-hours produced at +22°C can probably be explained by the increased internal resistance of the cell. Even though the current is smaller at the low temperature tests the voltage plateaus occur at lower levels than they did at +22°C. This can be attributed to the increased internal resistance which causes more voltage drop for a given current. Thus, the load voltage falls below its last useful level before the cell can be completely discharged.

<u>f. Results of the 0°C Test.</u> Results of the 0°C test are shown in Table 4-9. At 0°C the inability of the Mallory cell to deliver power at useful voltages at low temperatures is clearly demonstrated in Figure 4-24. The RCA cell (Figures 4-20 and 4-21) show a small increase in watt-hours from -10°C although the voltage characteristics are similar, both having a long tail-off, thus making the choice of end points somewhat arbitrary. The Yardney performance (Figures 4-22 and 4-23) does not match that at room temperature although discharge is longer than at room temperature (for similar reasons noted under the -10°C tests) with the 22-ohm load.

<u>g. Results of Tests on Nickel-Cadmium Cells.</u> The entire group of nickel-cadmium cells was provided with load resistors that would discharge them in approximately five hours. Figures 4-25 through 4-33 show the typical performance of the cells tested. In most cases the voltages were constant for five hours, but then dropped to useless values in a matter of minutes. It is believed that these cells, being rechargeable, would be more successful where they could be operated in conjunction with charging facilities such as a solar battery installation.

TABLE 4-9

RESULTS AT 0°C

CELL IDENTITY	END VOLTAGE	WATT-HOURS	WATT-HOURS PER POUND
RCA BATTERY (50-OHM LOAD)			
237	1.0	2.12	32.1
239	1.0	0.61	9.2
13	1.0	1.72	26.0
14	1.0	1.46	22.1
15	1.0	1.62	24.4
16	1.0	1.94	29.4
17	1.0	1.78	26.8
18	1.0	1.64	24.8
237	0.8	32.9	
239	0.8	26.0	
MALLORY BATTERY (10-OHM LOAD)			
21	1.10	0.21	0.58
22	1.10	0.39	1.08
23	1.10	0.38	1.05
24	1.10	0.28	0.77
25	1.10	0.27	0.75
26	1.10	0.15	0.42
YARDNEY BATTERY (6-OHM LOAD) (THIRD CYCLE)			
2	1.40	9.25	33.8
4	1.40	9.25	33.8
6	1.40	9.96	36.4
L(22-OHM LOAD) (FIRST CYCLE)			
19	1.50	8.07	29.4
20	1.50	7.55	27.6
21	1.50	8.28	30.2
22	1.50	8.58	31.3
23	1.50	8.13	29.6

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0°C COLD TEST

CELL VOLTAGE VS TIME FOR RCA CELL UNDER LOAD

AVG. TEMP. 0°C
LOAD 50...

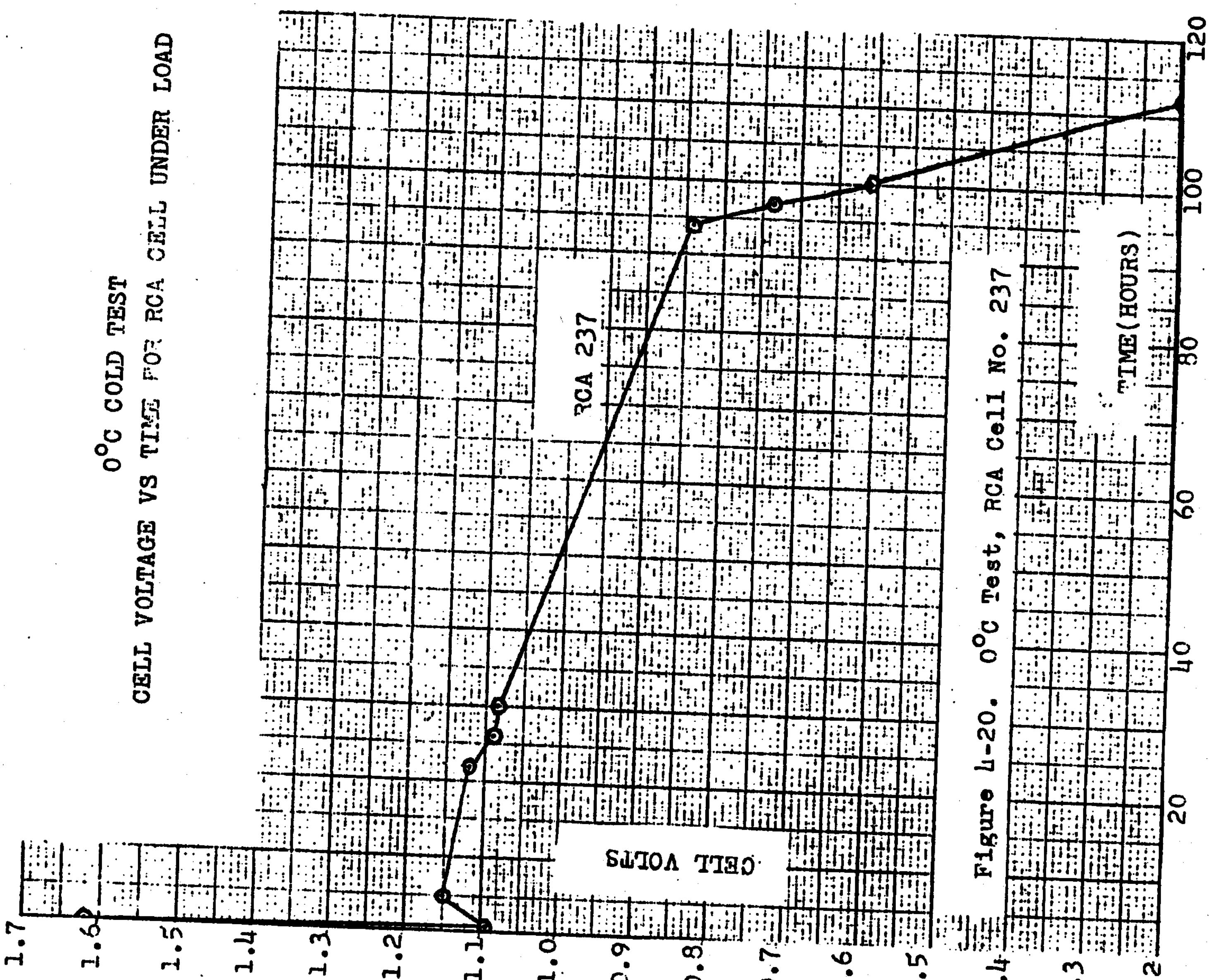

Figure 4-20. 0°C Test, RCA Cell No. 237

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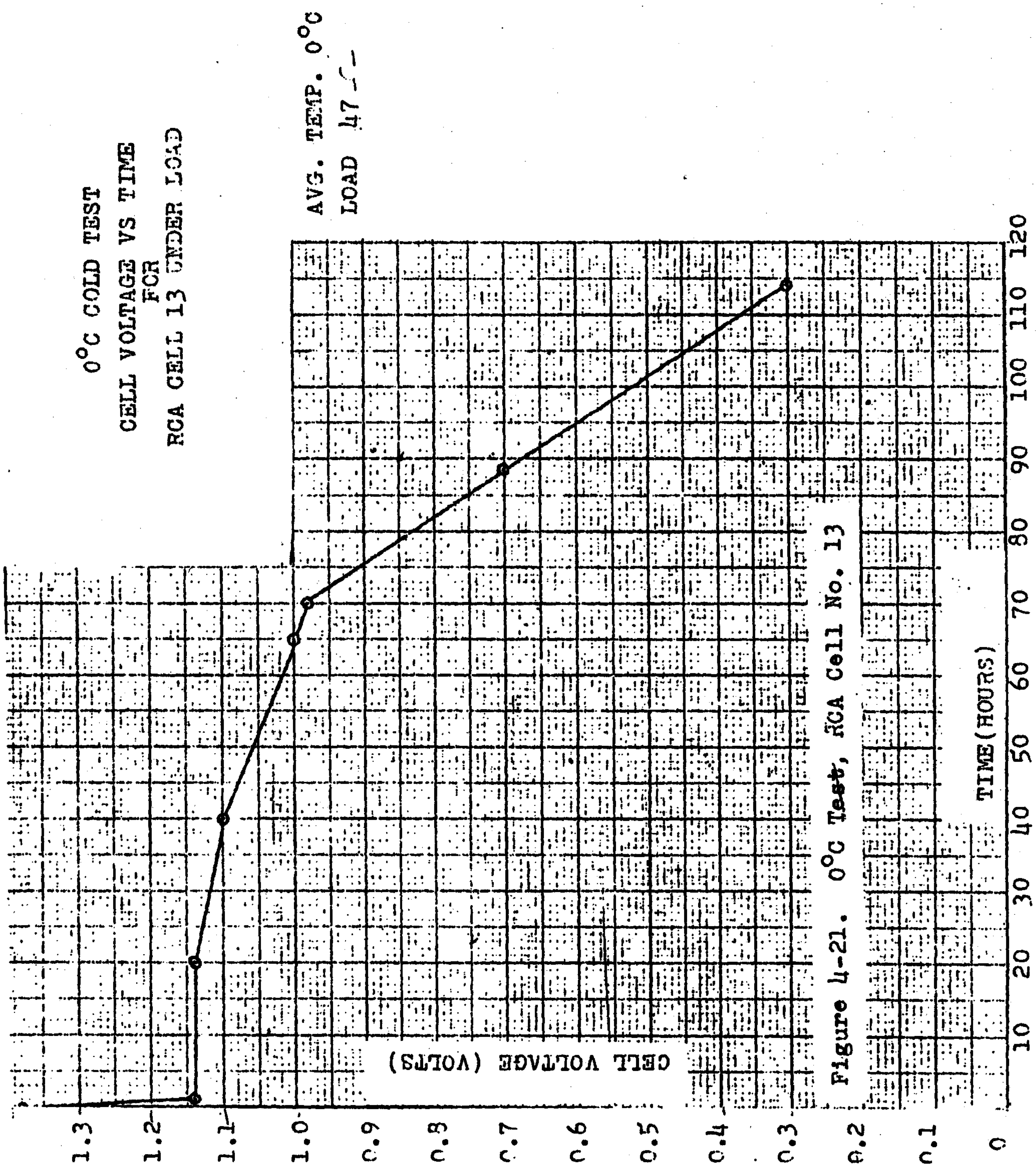

Figure 4-21. 0°C Test, RCA Cell No. 13

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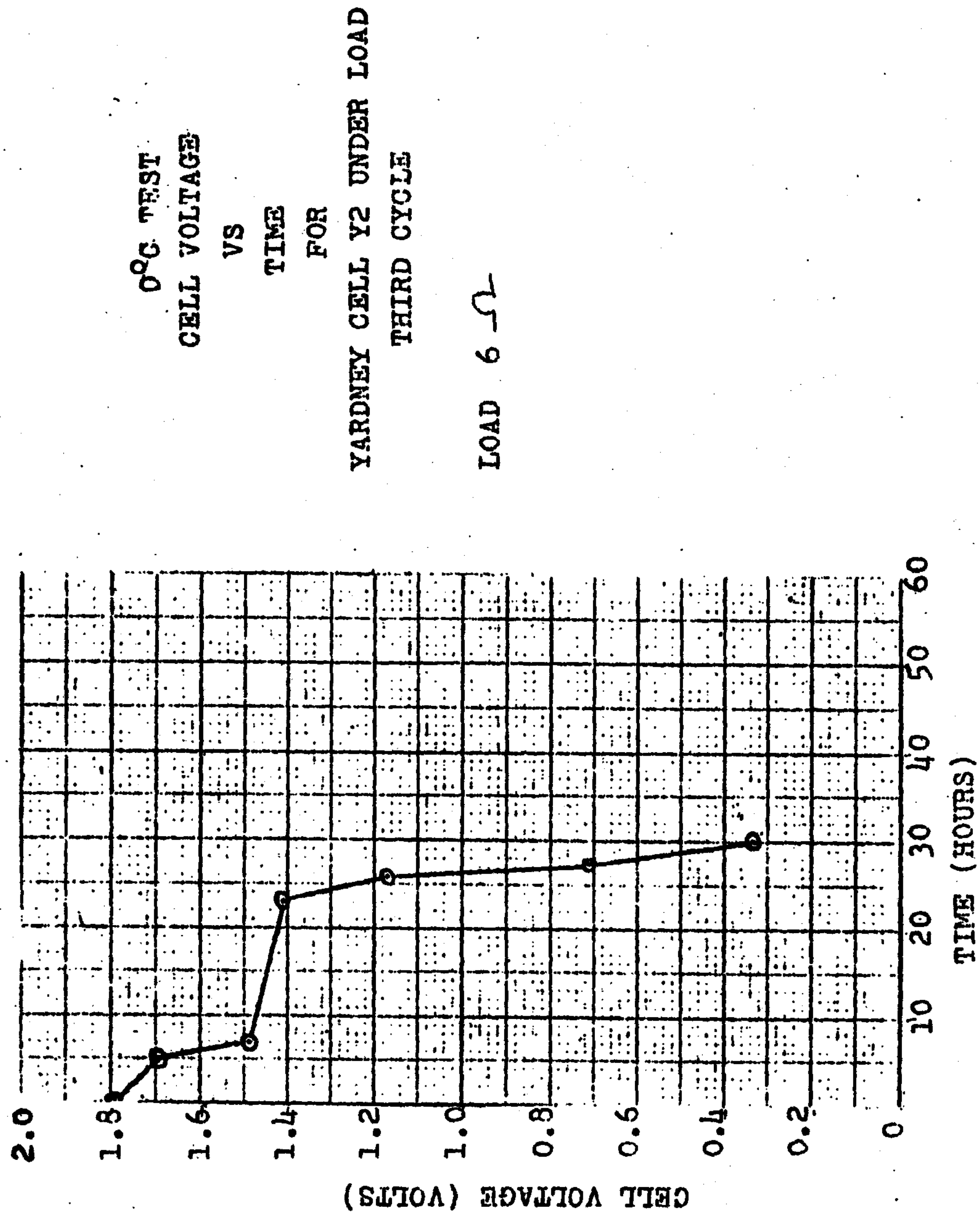


Figure 4-22. 0°C Test, Yardney Cell Y2 (Third Cycle)

0°C COLD TEST

CELL VOLTAGE VS TIME FOR YARDNEY CELL 19 UNDER LOAD

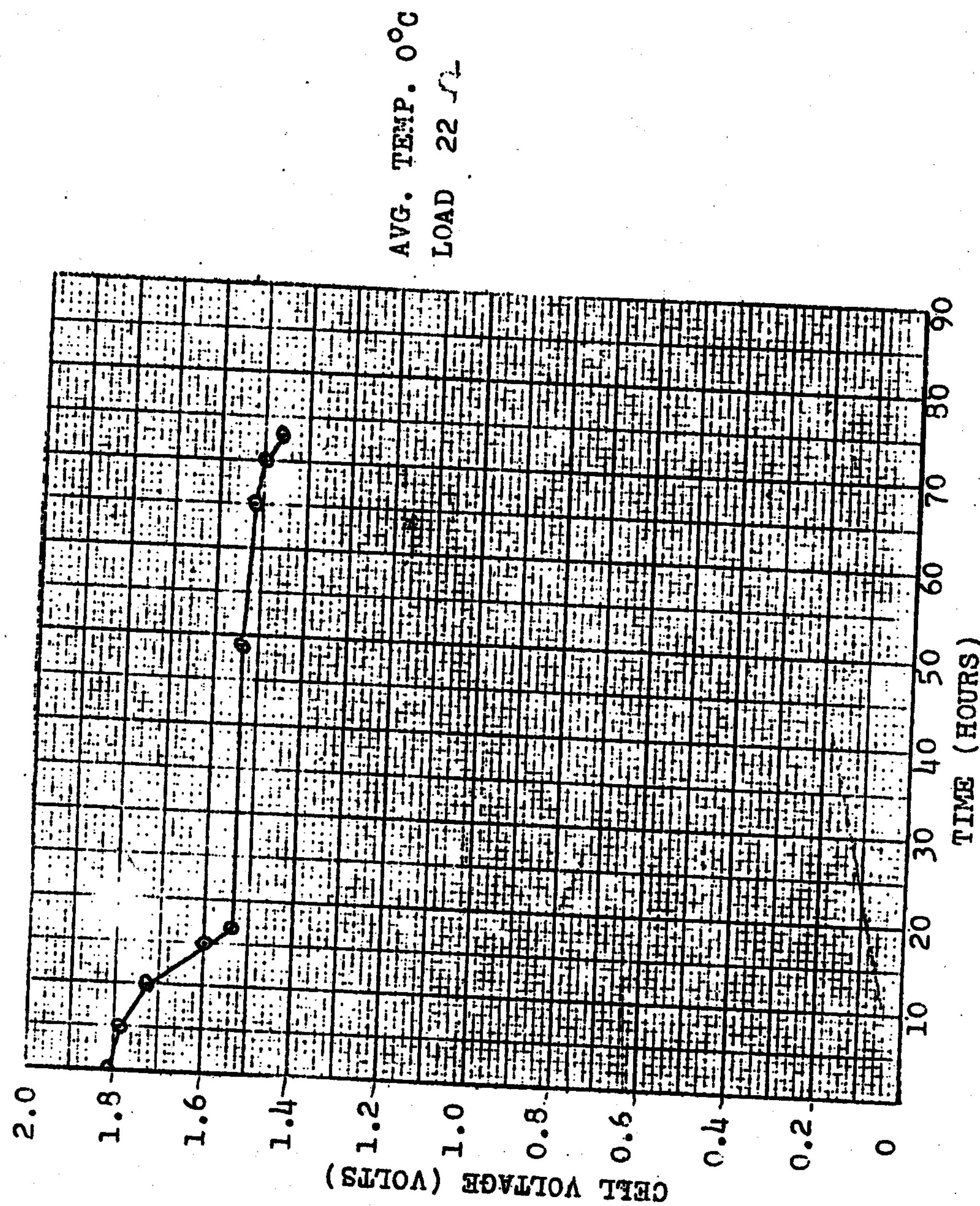
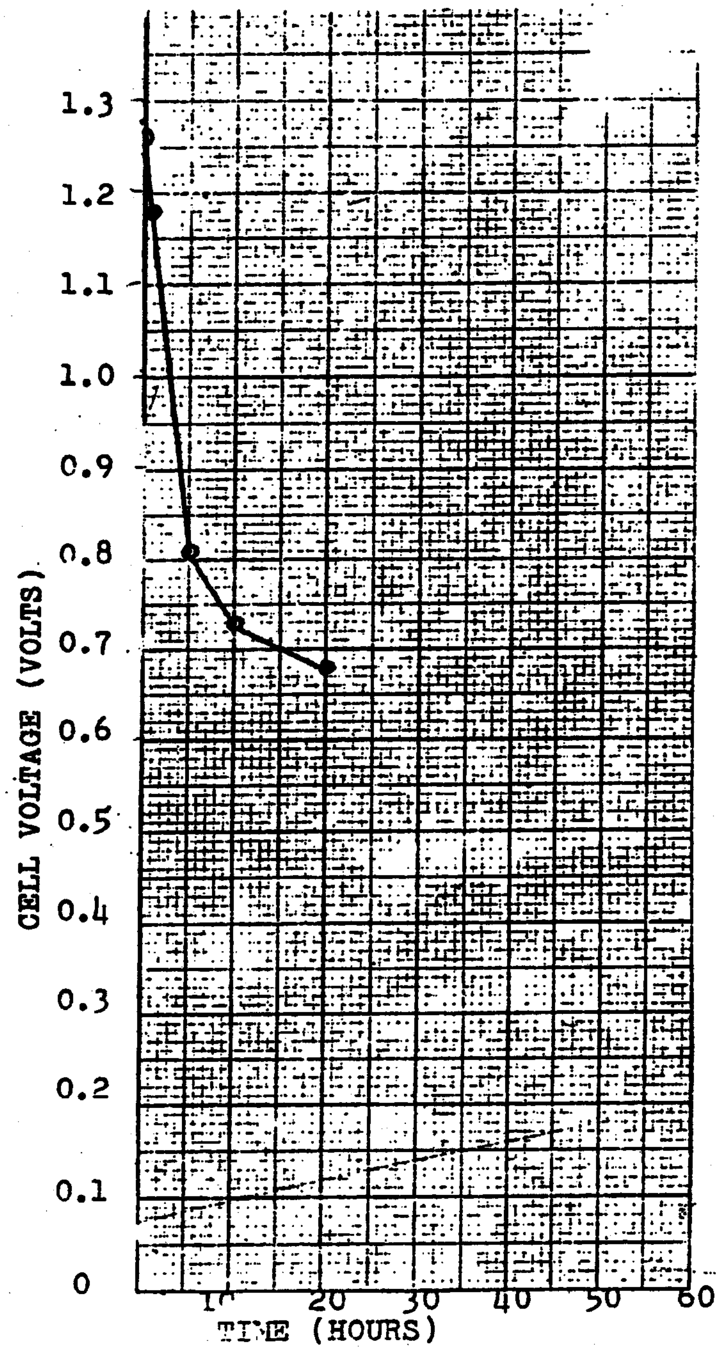


Figure 4-23. 0°C Test, Yardney Cell No. 19



0°C COLD TEST
CELL VOLTAGE
VS
TIME
FOR
MALLORY CELL 25
UNDER LOAD

AVG. TEMP. 0°C
LOAD Ω

Figure 4-24. 0°C Test, Mallory Cell No. 25

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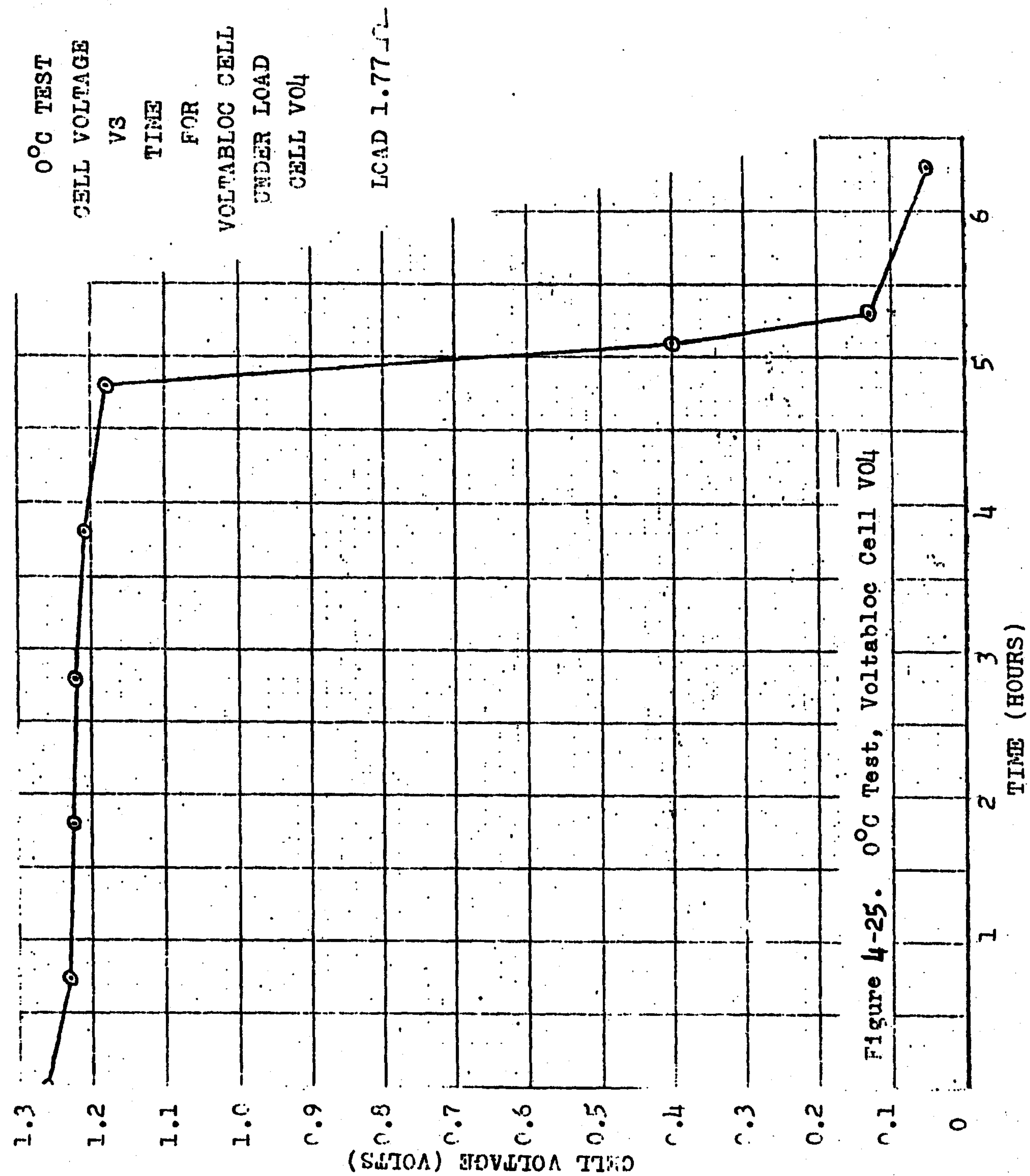

Figure 4-25. 0°C Test, Voltabloc Cell VO4

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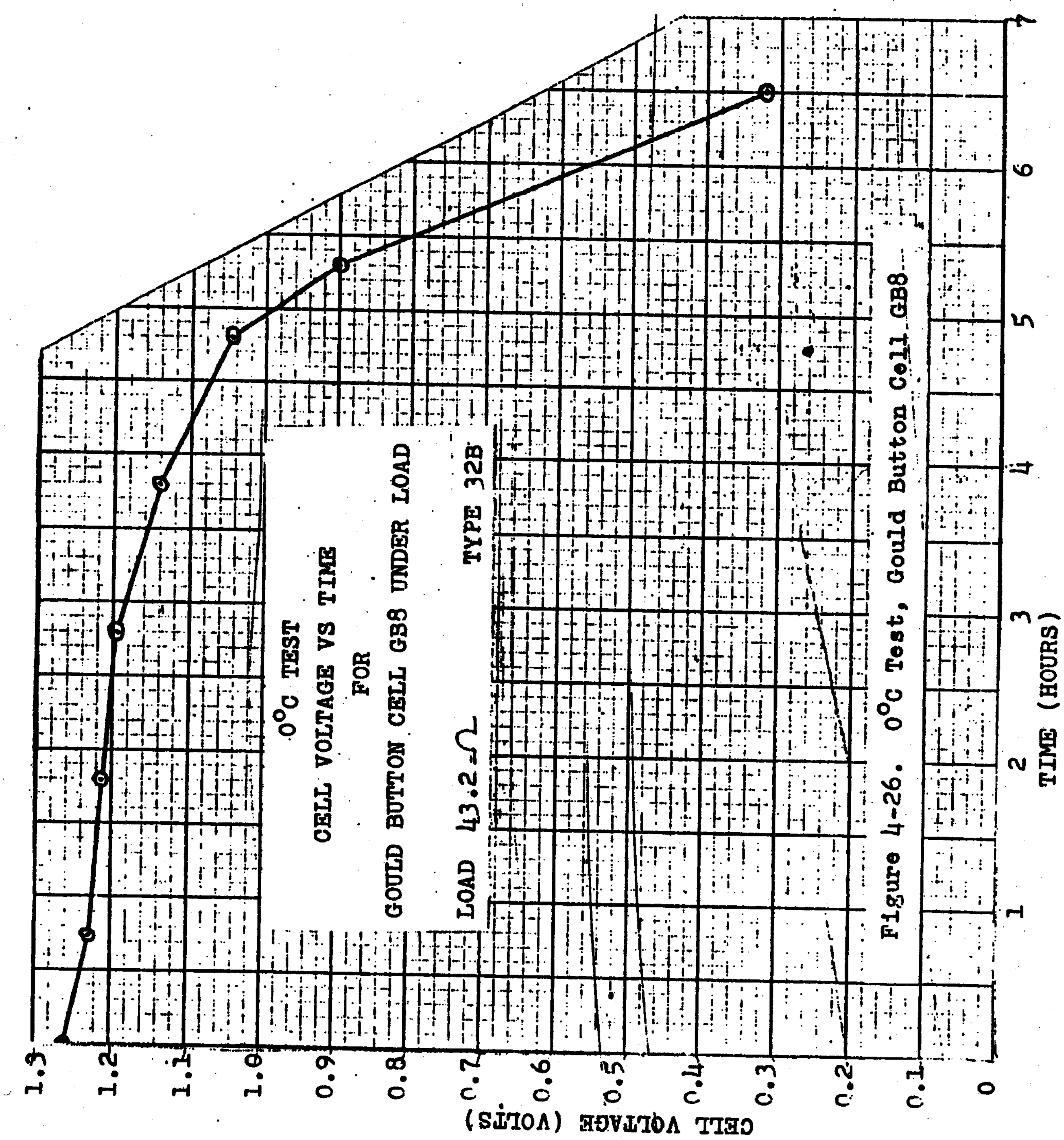

Figure 4-26. 0°C Test, Gould Button Cell GB8

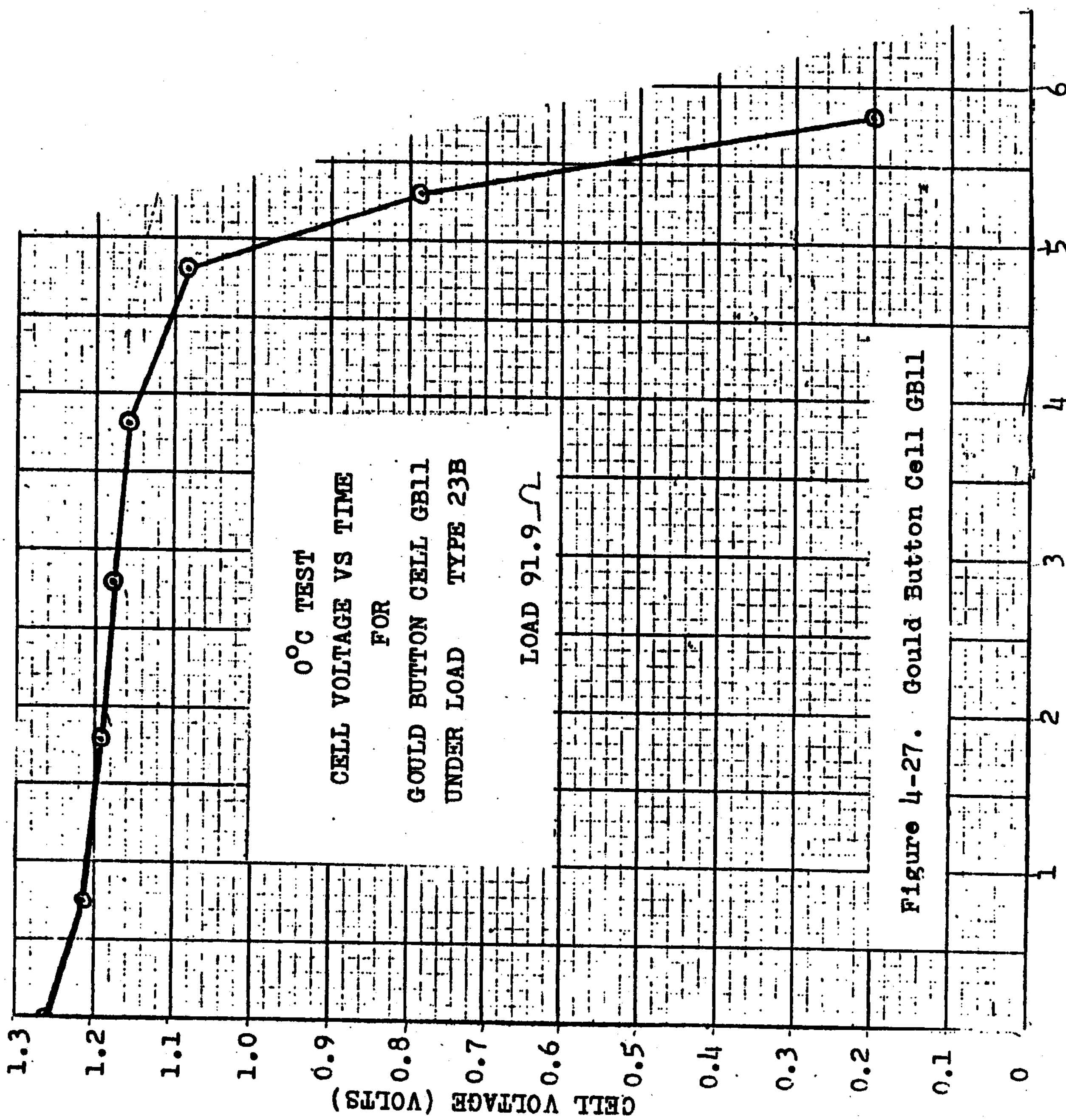

Figure 4-27. Gould Button Cell GB11

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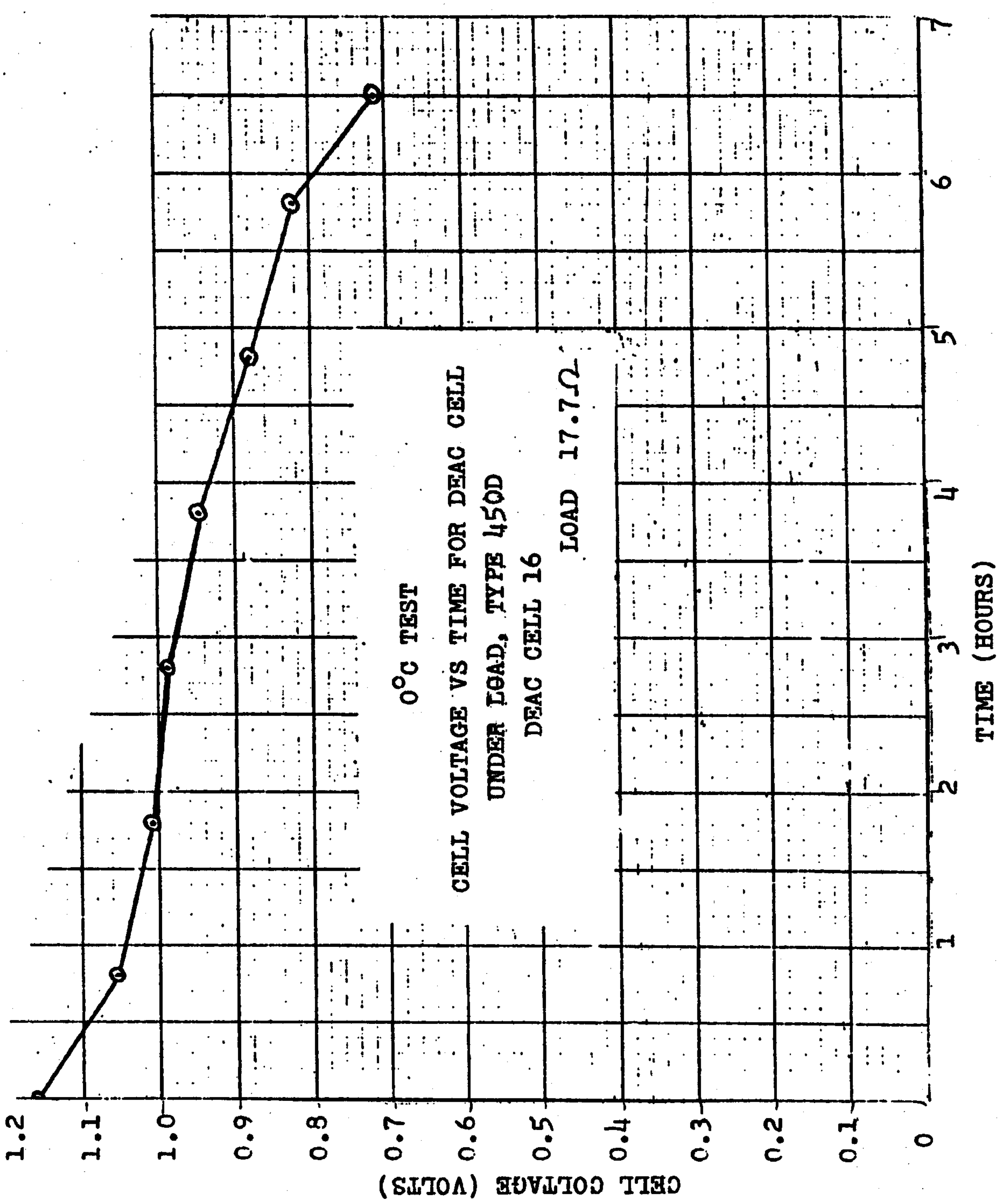

Figure 4-28. 0°C Test, Deac Cell, Type 450D, No. 16

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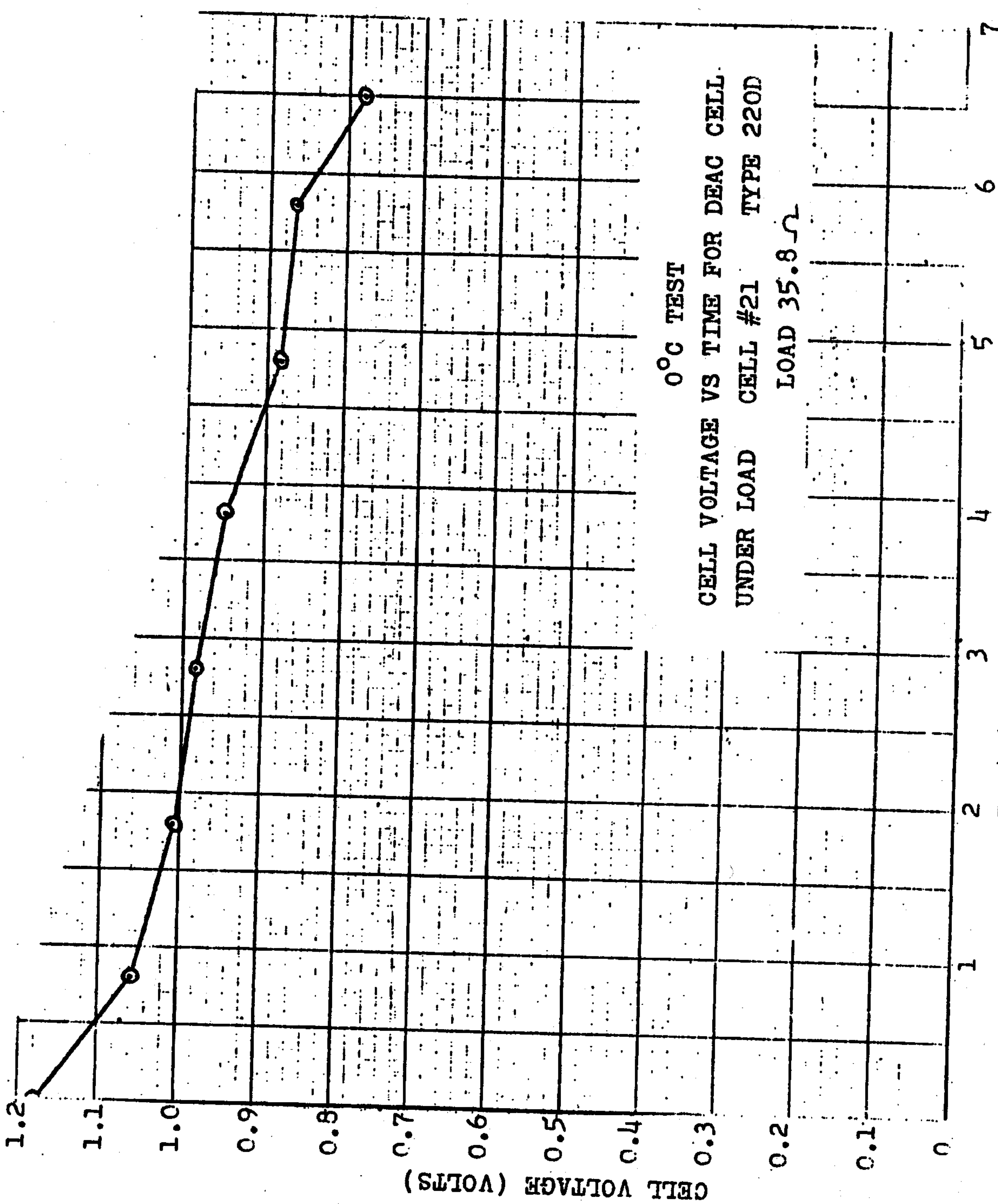

Figure 4-29. 0°C Test, Deac Cell, Type 220D, No. 21

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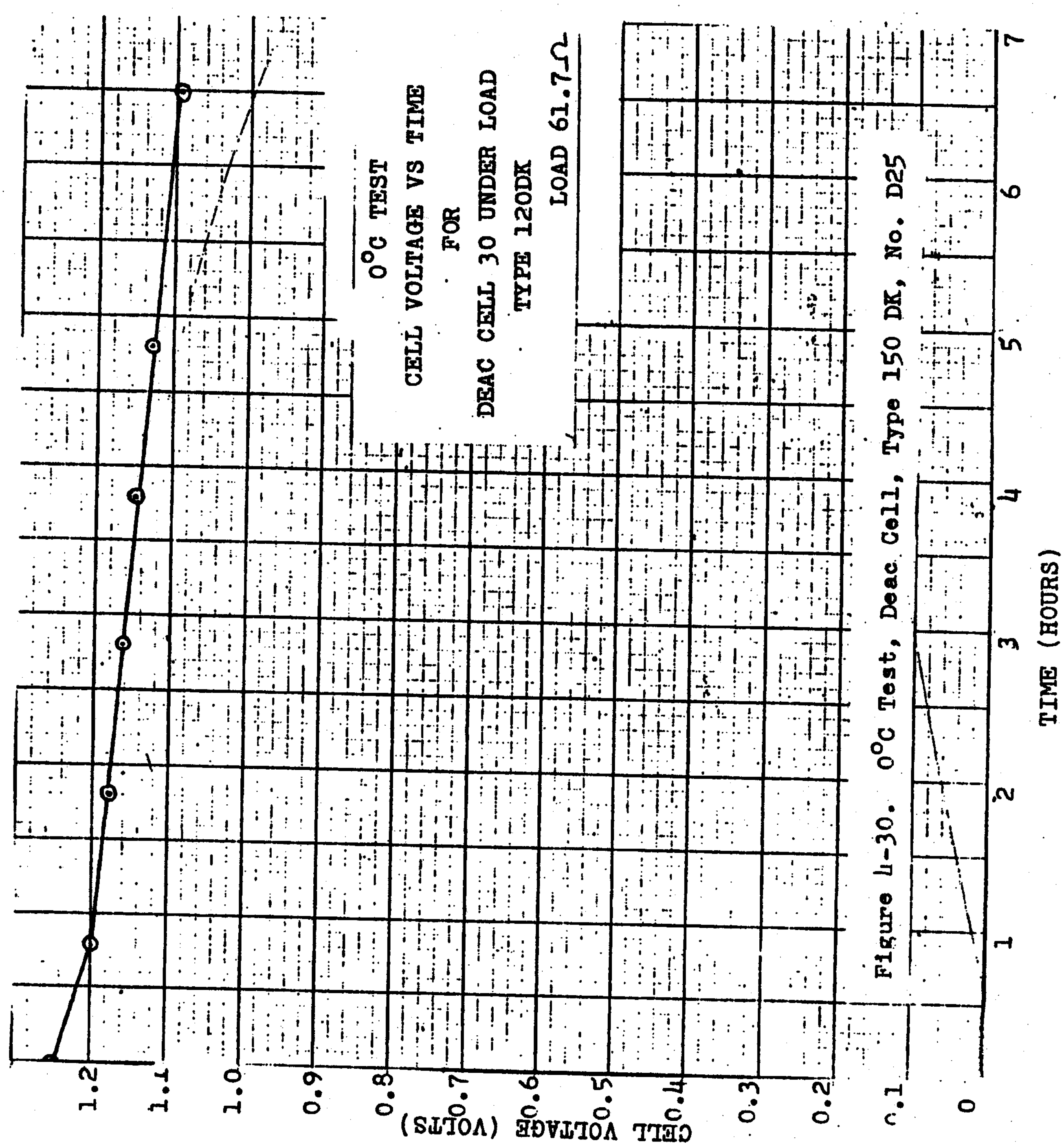

Figure 4-30. 0°C Test, Deac Cell, Type 150 DK, No. D25

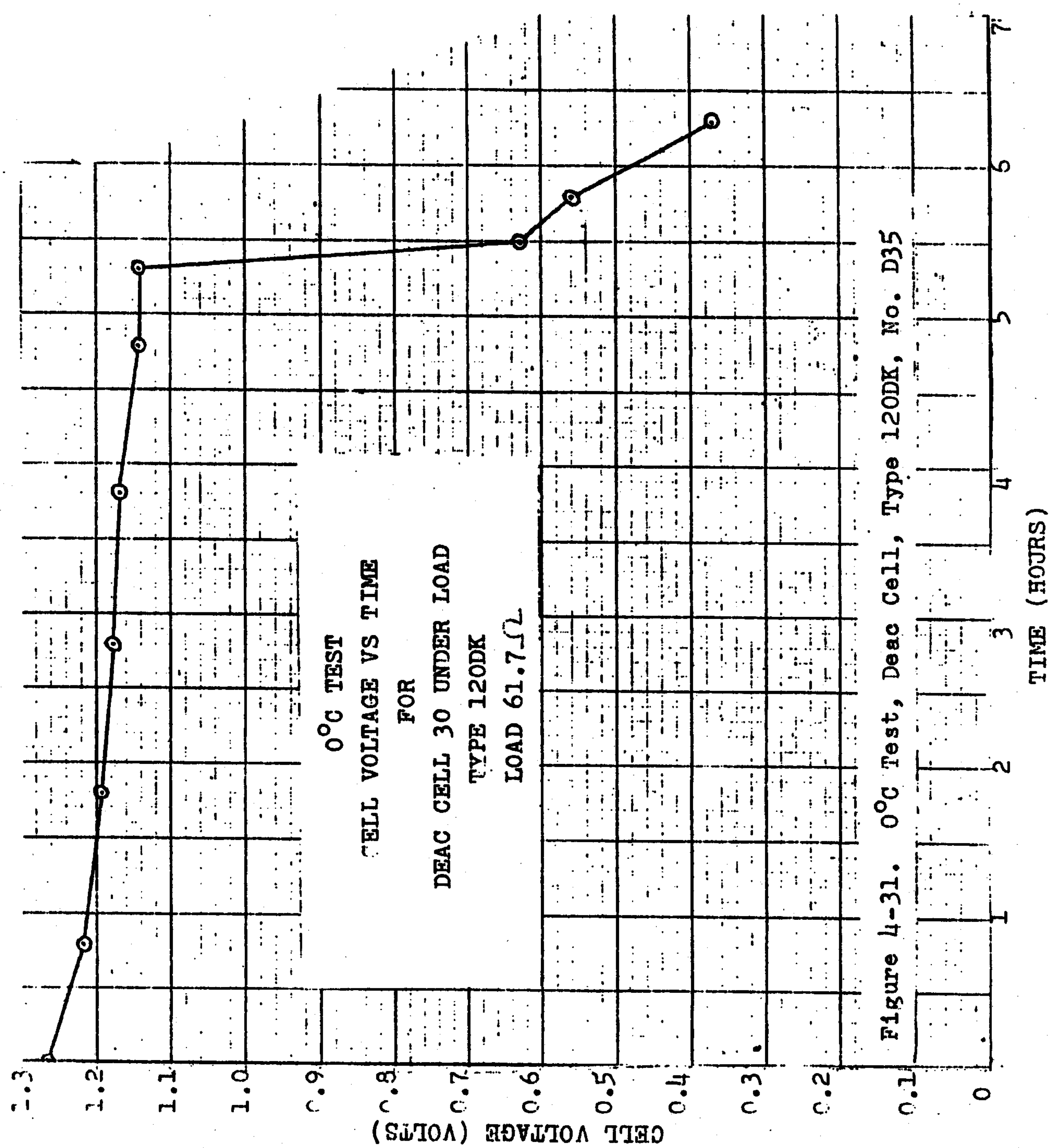

Figure 4-31. 0°C Test, Deac Cell, Type 120DK, No. D35

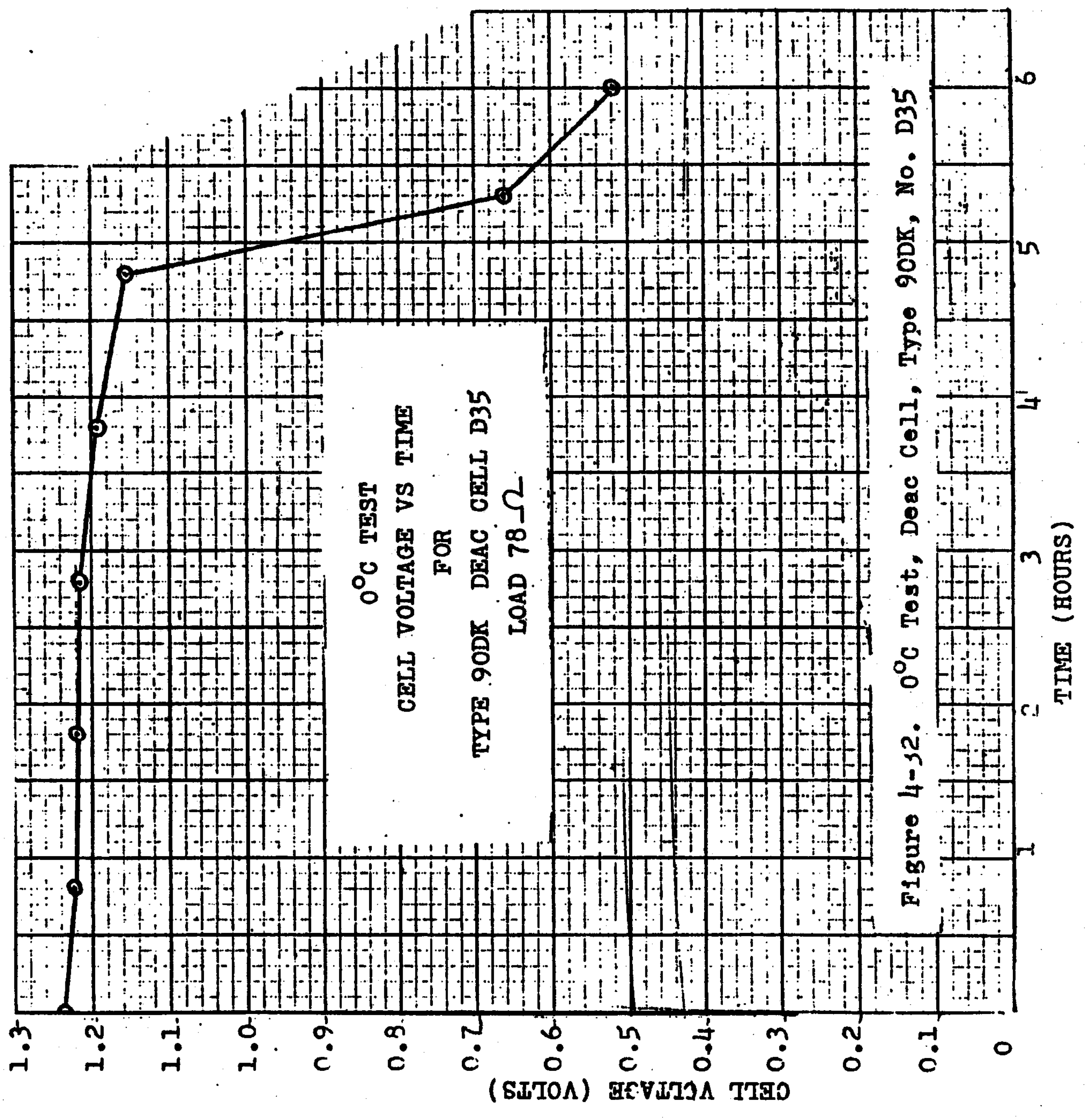

Figure 4-32. 0°C Test, Deac Cell, Type 90DK, No. D35

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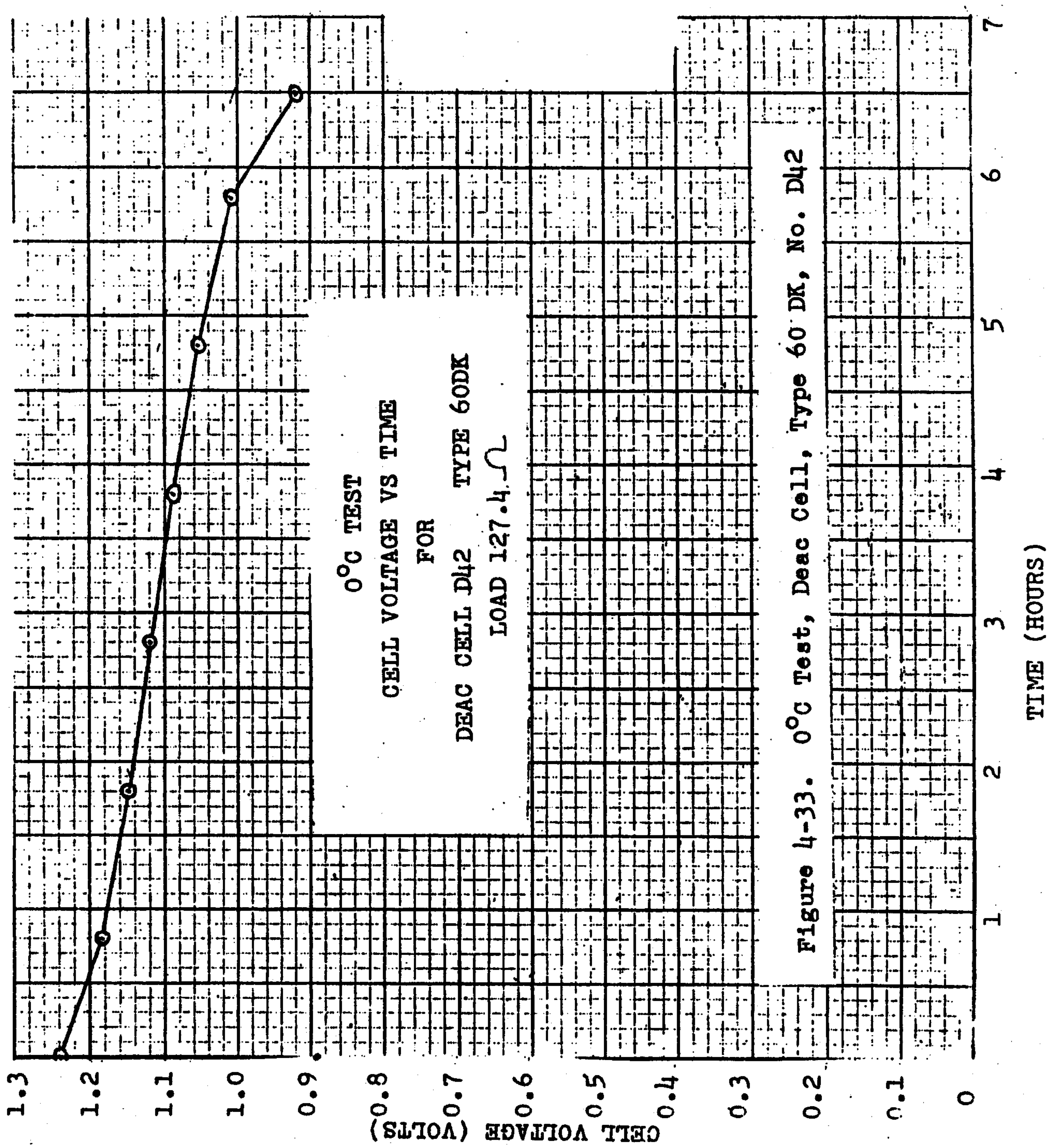

Figure 4-33. 0°C Test, Deac Cell, Type 60 DK, No. D42

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TABLE 4-10
RESULTS OF 0°C TEST ON VOLTABLOC,
GOULD BUTTON AND DEAC CELLS

CELL TYPE	END VOLTAGE	WATT-HOURS	WATT-HOURS PER POUND
VO4	0.13	4.11	11.0
	0.13	4.48	11.9
	0.06	5.01	13.4
GB32B	0.32	0.195	6.05
	0.76	0.216	6.71
	0.82	0.230	7.15
GN23B	0.08	0.0824	6.29
	0.80	0.102	7.74
	0.10	0.0918	7.02
DEAC 450D	0.725	0.348	7.00
	0.64	0.294	5.90
	0.74	0.354	7.11
DEAC 220D	0.78	0.172	6.21
	0.88	0.188	6.83
	0.928	0.189	6.87
DEAC 150DK	1.1	0.178	8.42
	1.13	0.183	8.65
	1.14	0.185	8.71
DEAC 120DK	0.37	0.139	7.15
	0.41	0.133	6.88
	0.44	0.147	7.60
DEAC 190DK	0.52	0.106	6.52
	0.56	0.108	6.64
	0.59	0.108	6.64
DEAC 60DK	0.92	0.0646	8.38
	1.03	0.0700	9.06
	0.96	0.0666	8.58

From the tabulated data (Table 4-10) it is obvious that all the cells suffered seriously at 0°C. The watt-hour per pound figures in no case are within 4 percent of the rated values and in most instances are down approximately 20 percent. The variation in end voltages is due to the failure of the cells after the conclusion of the working day.

TABLE 4-11

Results at +10°C

CELL IDENTITY	END VOLTAGE	WATT-HOURS	WATT-HOURS PER POUND
RCA BATTERY (50-OHM LOAD)			
I	1.00	2.64	39.8
L	1.00	2.32	35.0
MALLORY (10-OHM LOAD)			
3	1.10	12.5	34.4
4	1.10	12.8	35.2

h. Results of the +10°C Test. (See Table 4-11) No Yardney cells were tested at +10°C because the results of the +22°C and 0°C runs suffice to fill in the performance capabilities of this cell. The RCA voltage characteristic (Figure 4-34) is superior to that at 0°C in respect to the magnitude of the voltage, levelness and duration of the discharge. Whereas operation at 0°C is poor for the Mallory cell (Figure 4-35) its operation is considerably improved at +10°C. The low temperature limit for the Mallory battery is therefore between 0°C and +10°C. Both the RCA and the Mallory cells fall considerably short of matching room temperature performance.

i. Physical Effects of Temperature Tests. The Mallory cells show no undesirable physical effects from the cold tests. The Yardney cells continue to deposit the blue-gray matter from the negative plates. The same Yardney cells were used in a number of

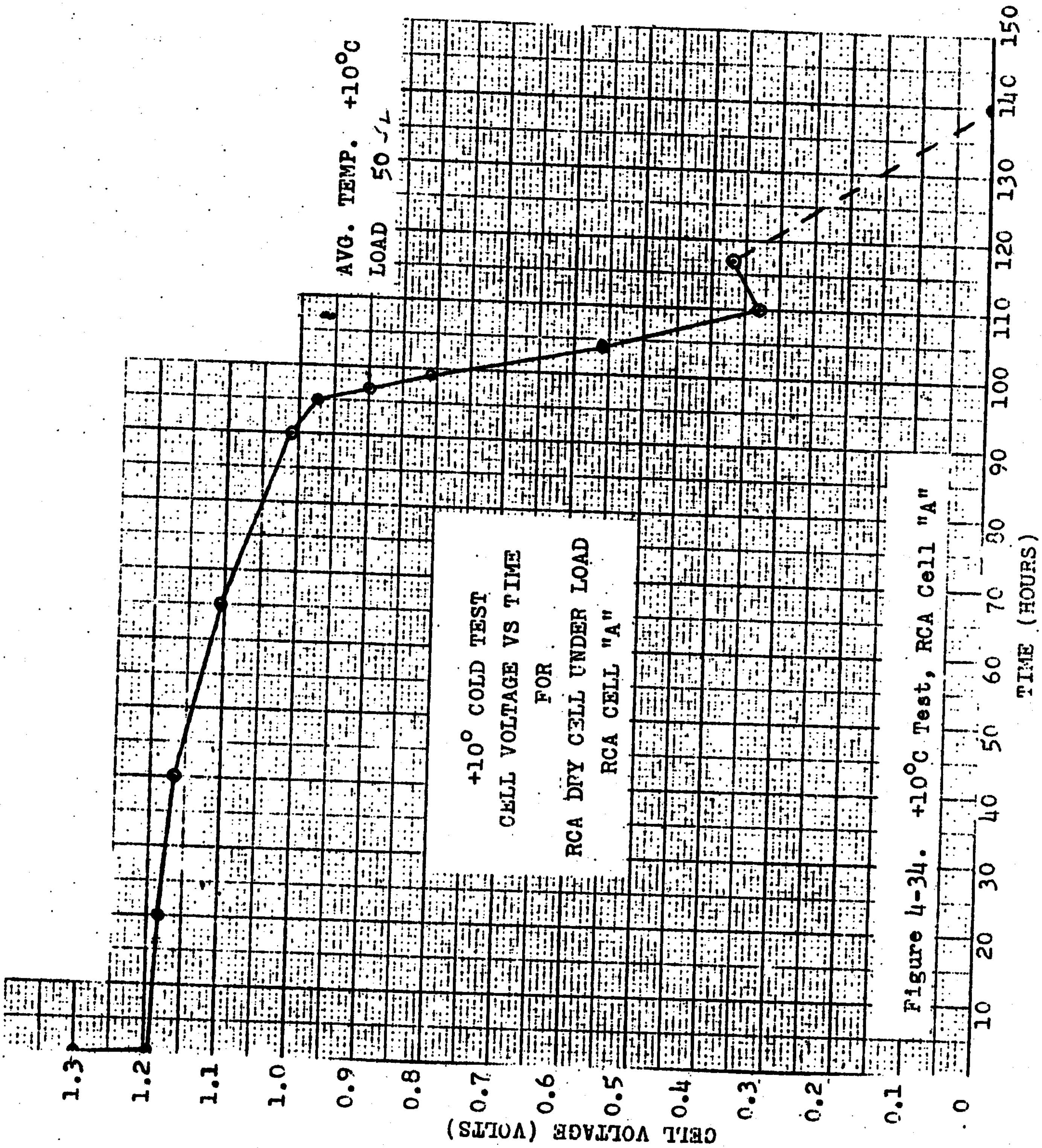

Figure 4-34. +10°C Test, RCA Cell "A"

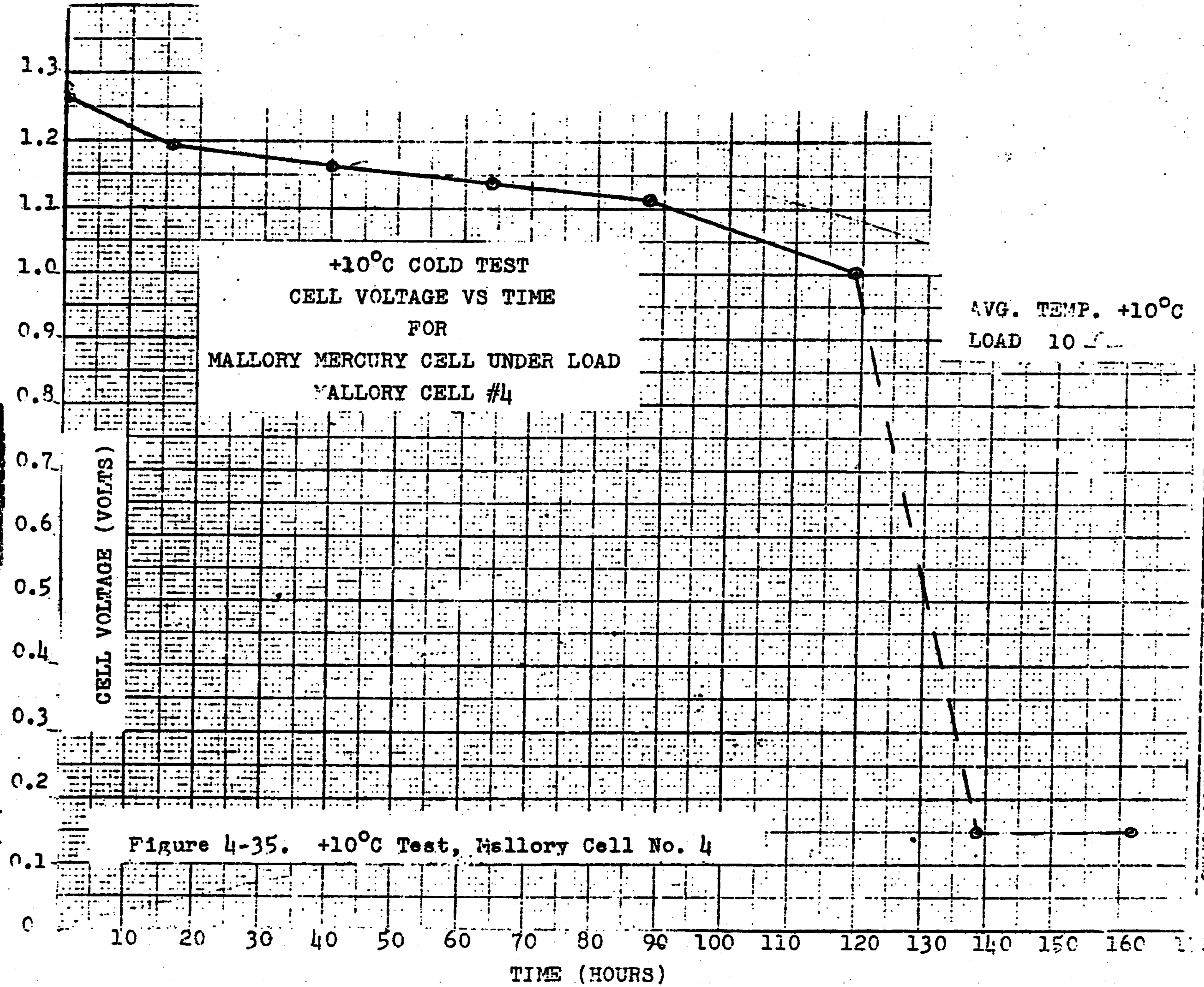

Figure 4-35. +10°C Test, Mallory Cell No. 4

different tests so that there was some deterioration of the cells with each succeeding test. After the first test with these cells (at -10°C) it was found that cell YI had shorted. This was caused by the excessive deposits of the blue-gray powder. After the second discharge Y2 at -20°C it was found that this cell had internal shorts. Subsequent tests failed to show similar failures in an additional quantity of 18 Yardney cells. The RCA cells also continued to suffer from the chemical reactions which destroyed the cell casing. At lower temperatures the effect was less pronounced and in many cases was much more in evidence near the ends of the cell where the wax seal joined the case. Upon being exposed to the warmer temperatures the reaction was stimulated and more of the case was engulfed in the reaction.

6. Summary of Temperature Tests:

Figure 4-36 shows watt-hours per pound as a function of temperature. These notes apply to Figure 4-36:

1) RCA battery - all points are for 1.0 volt end point
2) Mallory battery - the -10°C is for 0.80 volt end point whereas all other points are for 1.10 volts.
3) Yardney battery - the end point voltage here is made to include the last voltage plateau. (1.5 volts for all runs except at -20°C where 1.2 volt was used).

The RCA battery yielded its largest watt-hour per pound figure at room temperature. Operation at lower temperatures reduced this number by at least one third. Higher than room temperature tests gave disappointing and inconsistent results. Expectations that the performance would be enhanced at these higher temperatures were not borne out.

The Mallory cell did not produce the watt-hours per pound that the RCA cell did, but it yielded more consistent results at higher temperatures. Low temperature operation was drastically impaired at even +10°C.

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PERFORMANCE OF BATTERY POWER SUPPLIES

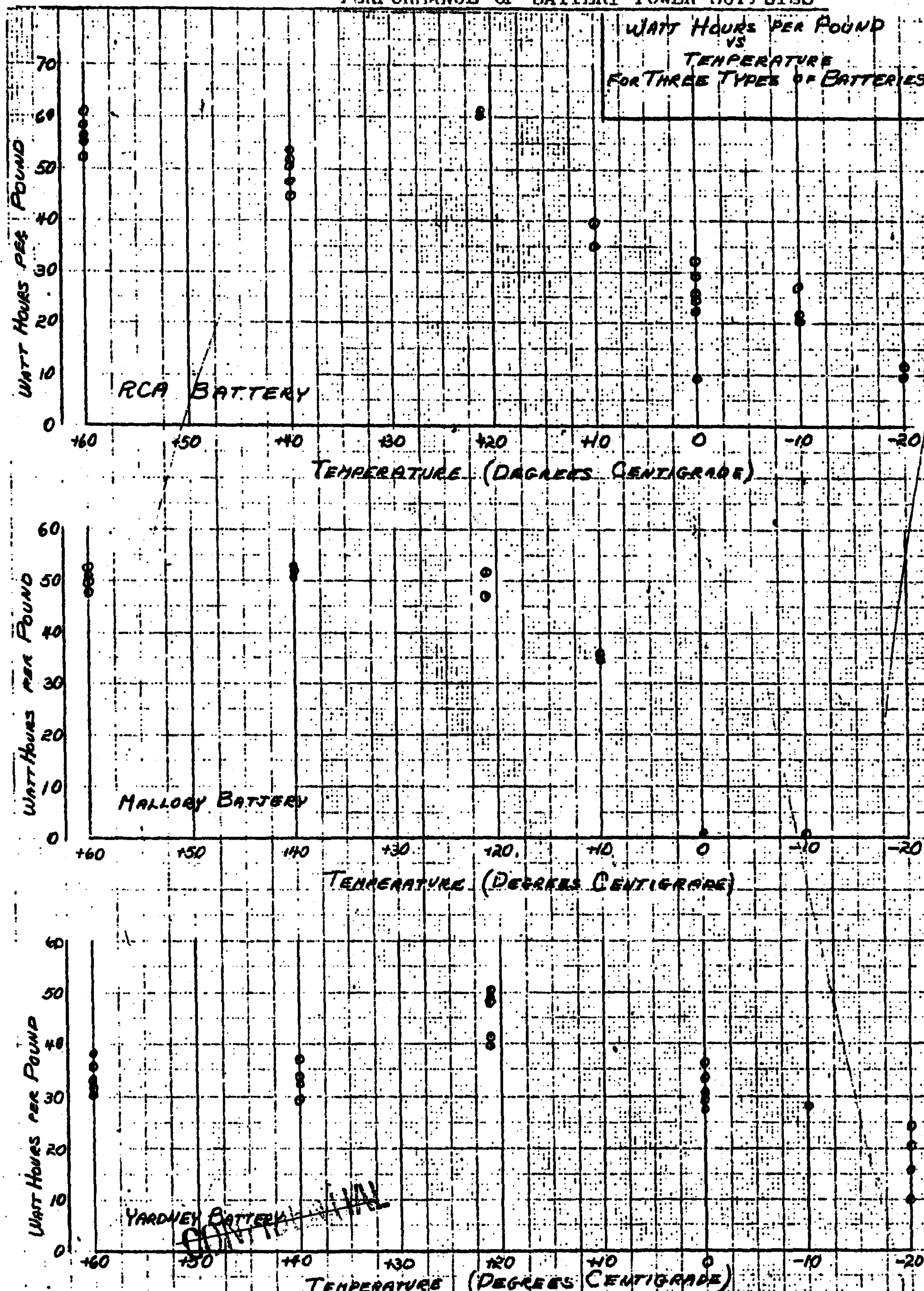

Figure 4-36. Watt-Hours Per Pound for the Three Types of Battery

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The Yardney cells yielded maximum energy at room temperature; they appear to just match Mallory performance in this range. The Yardney output was reduced approximately 20 percent at the higher temperatures. However, the performance at low temperatures was greatly superior to that of the Mallory and RCA cells.

It is to be stressed that all the low temperature data are pessimistic because of the effect of internal resistance at these temperatures. The voltage characteristic for the Yardney cell at -10°C when compared to the results at neighboring temperatures illustrates the decided advantage of low drain. It is to be expected that the watt-hours per pound and voltage characteristics of the RCA and Mallory cells would be improved considerably by reducing the drain by a factor of five. Certainly a higher and more constant voltage characteristic and a higher watt-hour figure would be the result.

From the graphical presentation it is observed that there is relatively large variation in the watt-hours per pound figure at any one temperature for one type of cell. This can be attributed to the differences in the cells. Certainly it would be desirable to test many more cells at the more desirable loads to obtain a more accurate picture of the performance capabilities of these batteries.

D. VACUUM TESTS

1. Purpose and Conditions

The vacuum tests were made to determine the rate of weight loss of the cells in a vacuum, the amount of moisture lost as a function of time in a vacuum, and the effect on open-circuit voltage. The tests were made at 0.005 to 0.002 mm of Hg at temperatures of +70°C, +50°C and +20°C under no-load conditions. The same cell types were tested in the vacuum as were given temperature tests. For comparison the weight loss of one RCA developmental cell was checked at room temperature and pressure for an extended period of time.

2. Test Equipment for the Vacuum Tests

A system was set up consisting of a motor and mechanical pump, a vapor trap, thermocouple vacuum gage (a type 1946 RCA tube) and bell jar. (See Figure 4-37.)

To insure accurate pressure readings the thermocouple gage was placed inside the bell jar with the batteries. With such a system it was possible to obtain pressures as low as 0.002 mm of mercury.

Moisture released by the batteries was collected in the vapor trap which was cooled with a mixture of alcohol and dry ice. Special sealing compounds were used at critical locations to prevent leakage. Those mountings that were placed in the bell jar were either of metal or bakelite since most other materials would give off gases or moisture when it was attempted to pump them down to a fraction of a millimeter of mercury. Before pumping was started the trap was loaded with the alcohol and dry ice mixture to insure that it would be cold enough to trap all the moisture from the very start of the pumping process. Of course a small amount of moisture from the air was trapped in this process. The moisture collected during pumping froze in the trap. To insure that all this moisture was recovered the trap was drained on the day following the pumping run so that complete melting could be assured.

For the experiments where the effect of combined vacuum conditions and heating was to be studied a special oven was constructed to hold the batteries. This container was wrapped with nichrome wire for the heating element. A thermometer with its bulb placed inside the heating box (all this inside the bell jar) indicated the temperature of the metal container and the batteries. Temperatures between room and +70°C were obtained with this arrangement.

Figure 4-37. Set-up for Vacuum Tests.

3. Test Results

Figure 4-38 gives the results of the pumping tests at room ambient temperature for three RCA cells. The most striking result is the very great difference in the results obtained. The total amount of moisture in the RCA cell is approximately 10 grams of which half is chemically combined and is not available. For RCA cell No. 258 over 3.5 grams or almost all the available moisture was removed after only 30 hours in the vacuum, the lowest pressure at any time being 0.05 mm of mercury. At this point its voltage (on open circuit) was reduced to less than 1.0 volt. RCA No. 12 lost 4 grams in 28 hours (down to 0.002 mm Hg) and this was enough to reduce its open circuit voltage to substantially less than 1.0 volt. RCA cell No. 248 was run for over 60 hours but lost only 1.34 grams and suffered no reduction in voltage. Although the results are inconsistent it is obvious that even at pressures of 0.002 mm of mercury these cells lose a large portion of their water. The relative success of RCA No. 248 is due to the superior seal used in this cell. Pressurization of these cells would probably be required for reliable operation in a vacuum. Note in Figure 4-39 that RCA cell C which was at room temperature has lost almost 0.60 gram after 1000 hours. This is regarded as a serious loss of moisture under room conditions and points to the need of a better seal.

The two Mallory cells were pumped for 65 hours to pressures as low as 0.002 mm of Hg yet lost less than 0.2 gram and suffered no reduction in open circuit voltage. (See Figure 4-38, curves M1 and M2.)

Six Yardney cells (Figure 4-40) were also tested open circuit at room ambient temperature. Two types of cells were tested, one with a rubber sponge type seal and the other a pressure valve seal. The valve seal will not open until the internal pressure exceeds 1.5 pounds per square inch. The sponge seal cannot hold any large

[redacted]

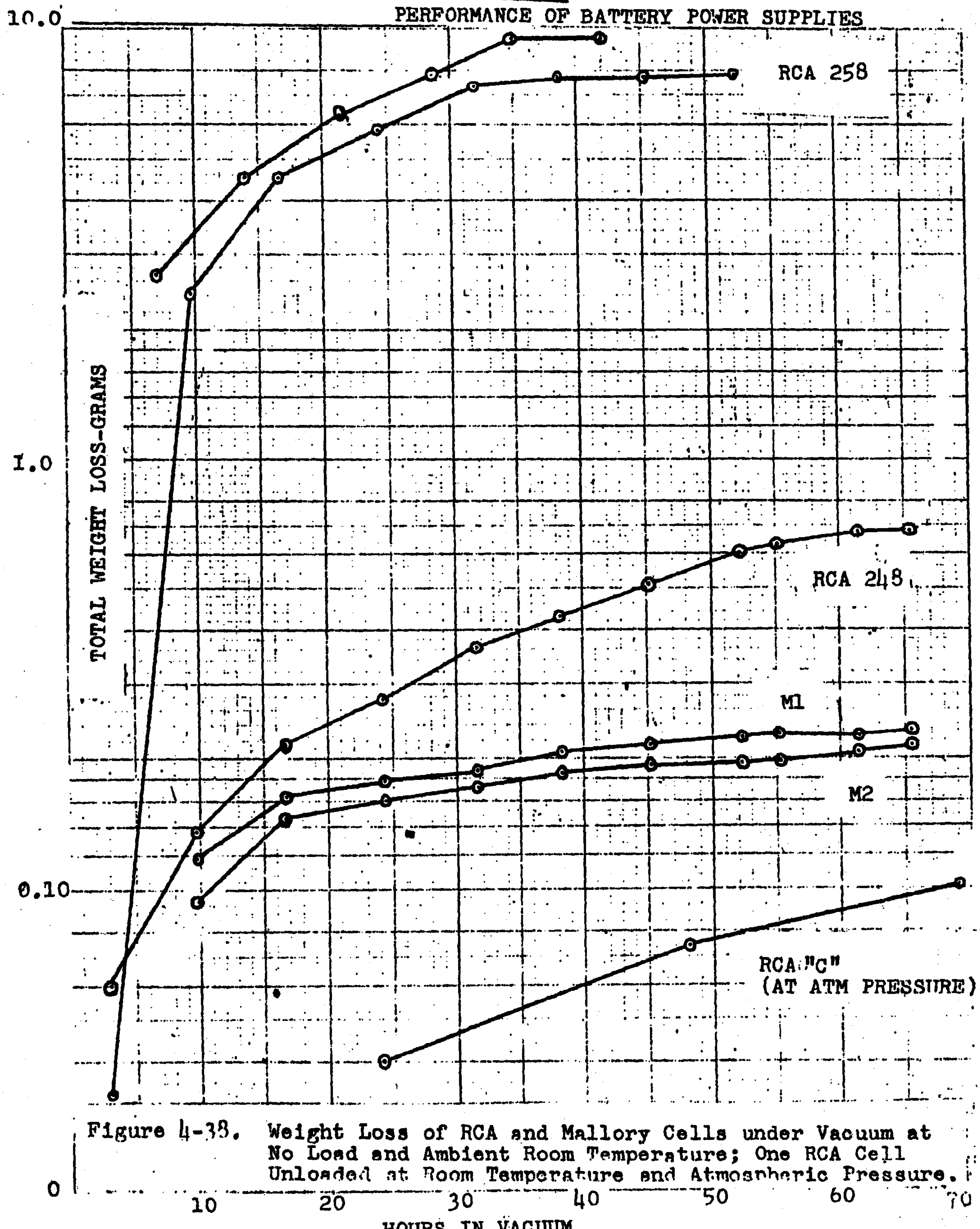


Figure 4-38. Weight Loss of RCA and Mallory Cells under Vacuum at No Load and Ambient Room Temperature; One RCA Cell Unloaded at Room Temperature and Atmospheric Pressure.

[redacted]

[redacted]

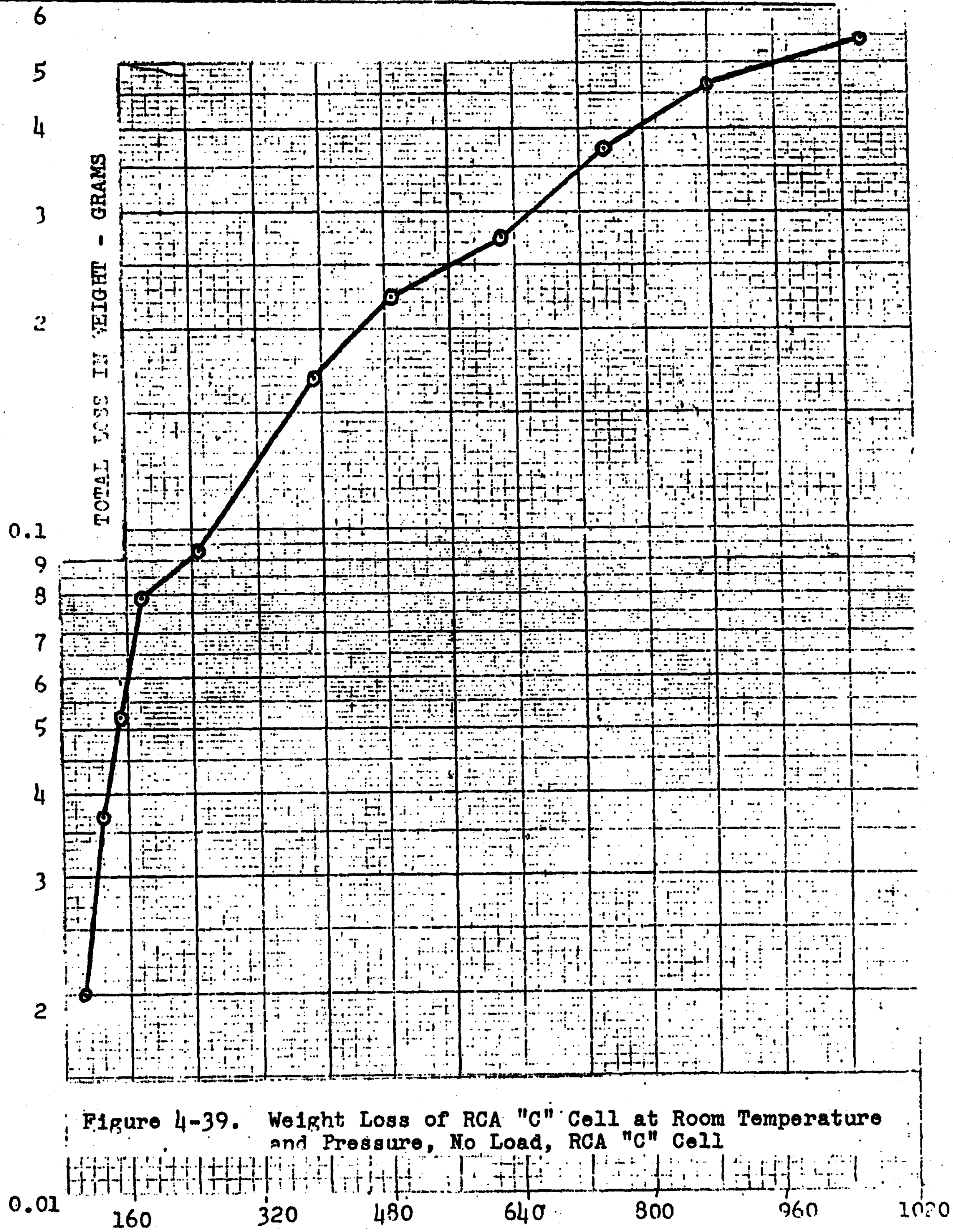


Figure 4-39. Weight Loss of RCA "C" Cell at Room Temperature and Pressure, No Load, RCA "C" Cell

[redacted]

[redacted]

CONF

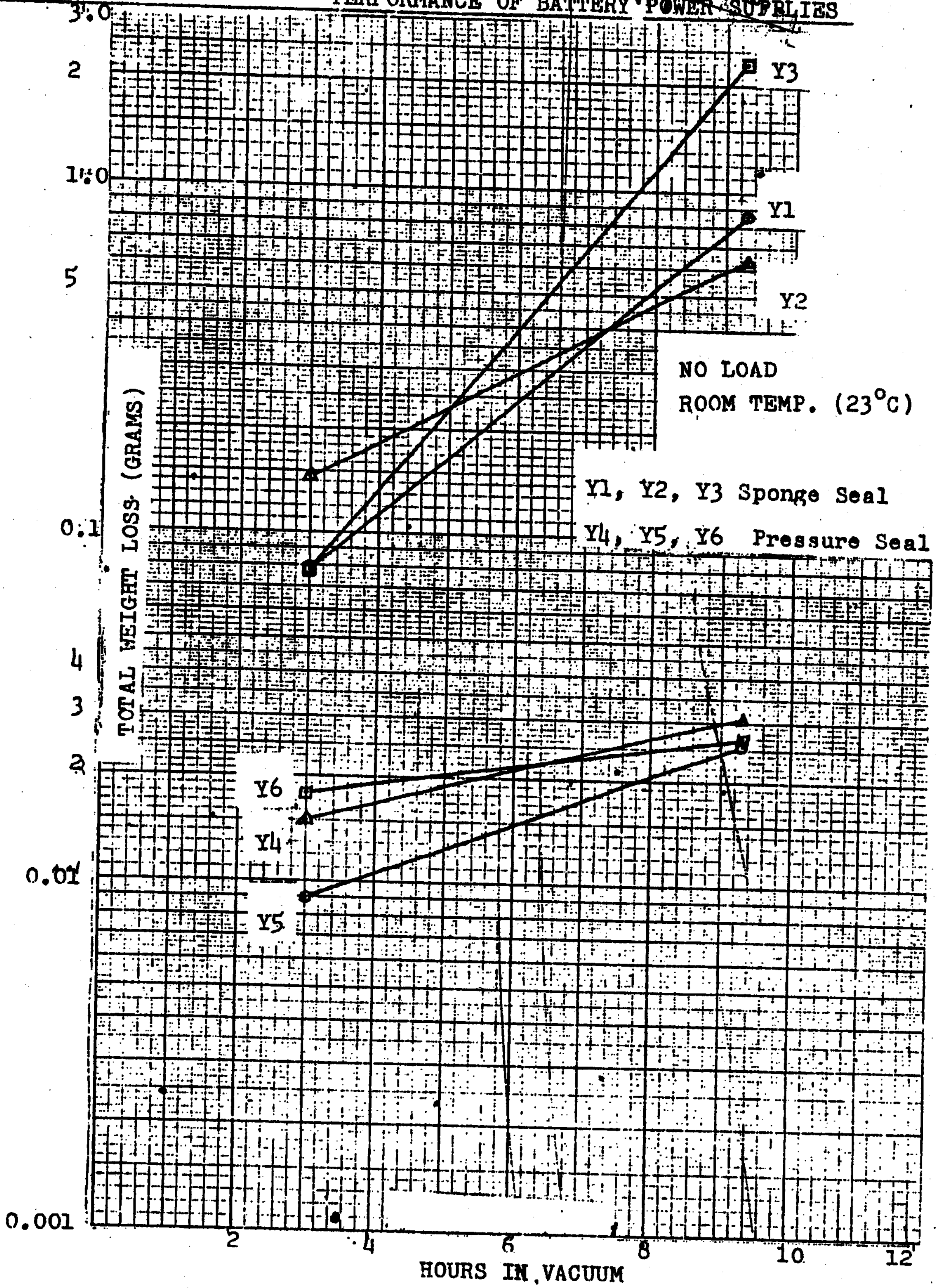


Figure 4-40. Weight Loss of Six Yardney Silvercells in a Vacuum.

[redacted]

CONF

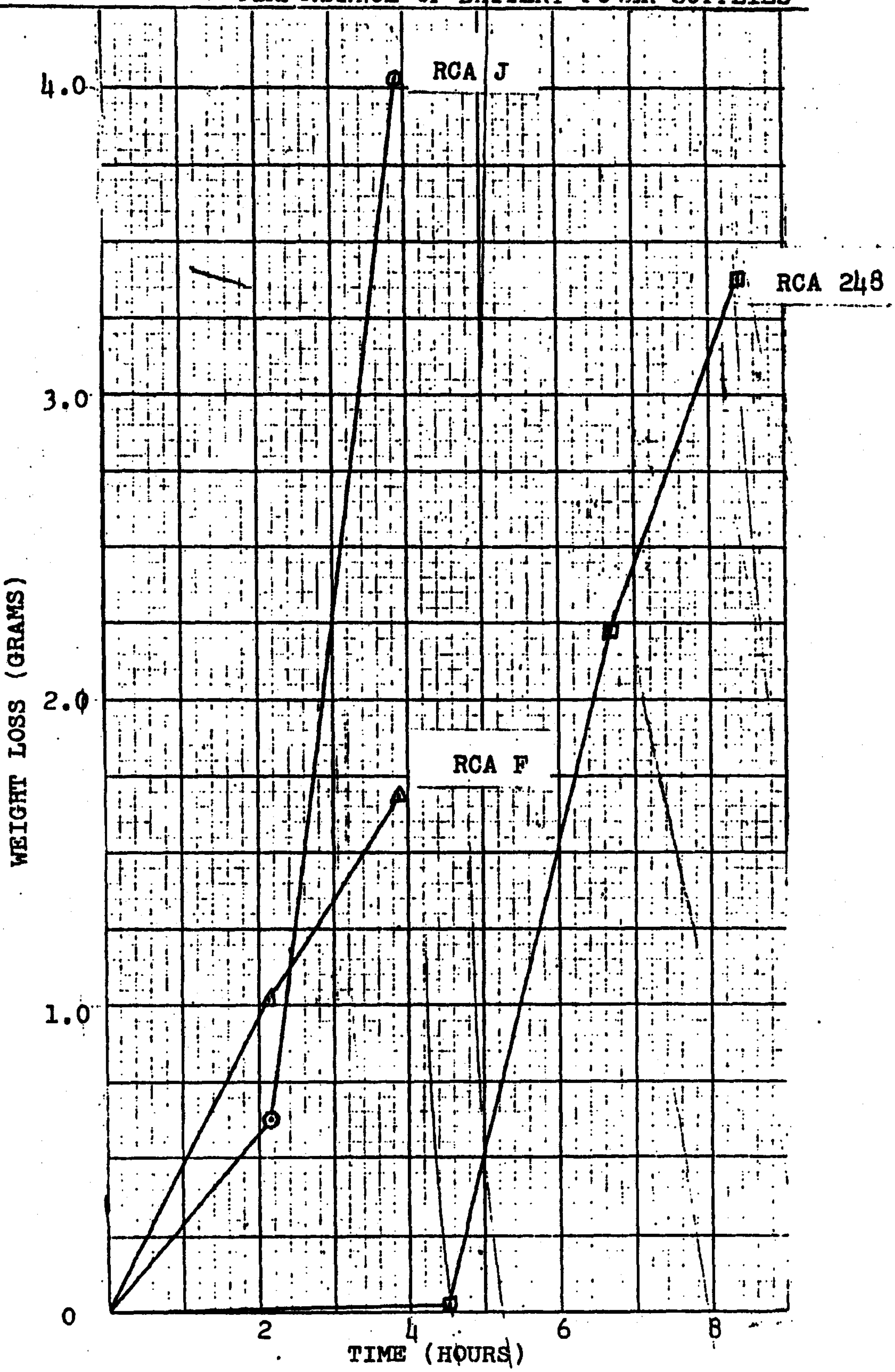


Figure 4-41. Weight Loss of Three RCA Cells under Load at 50°C in a Vacuum.

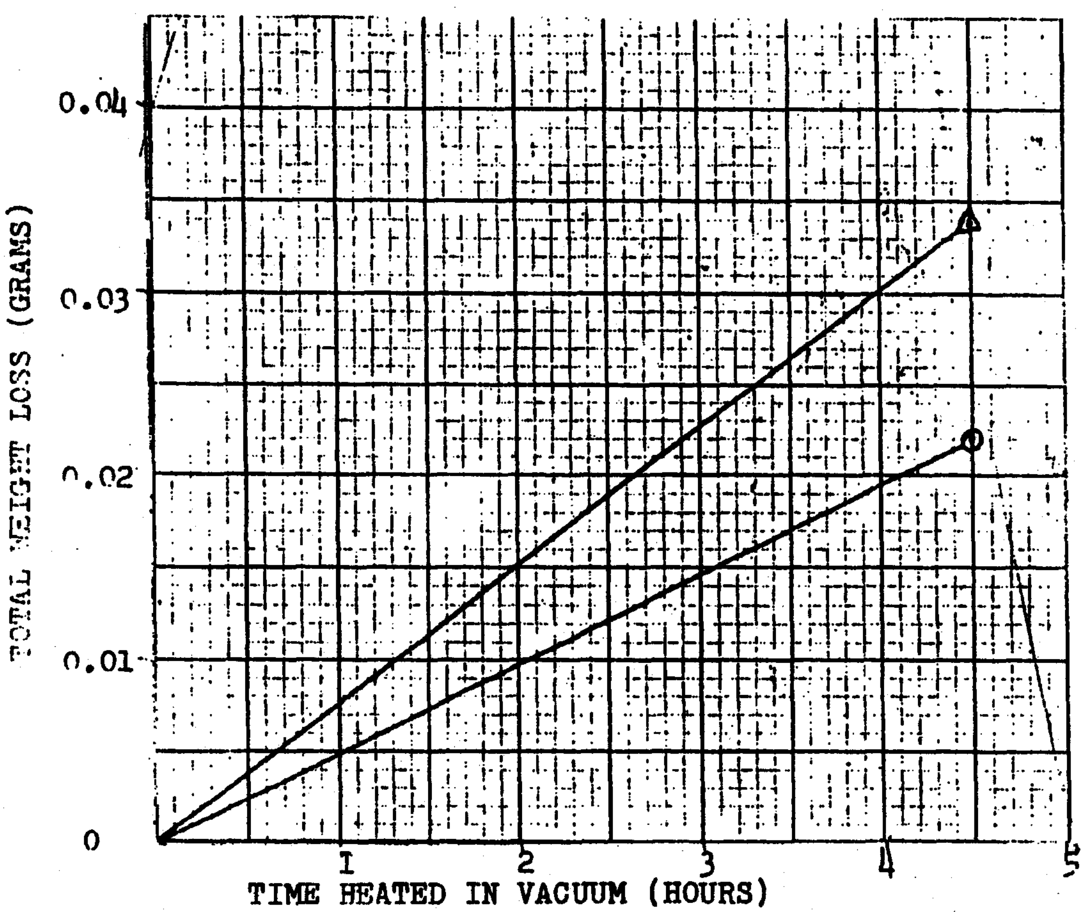


Figure 4-42. Weight Loss of Two Pressure-Sealed Yardney Silvercells in a Vacuum at 50°C.

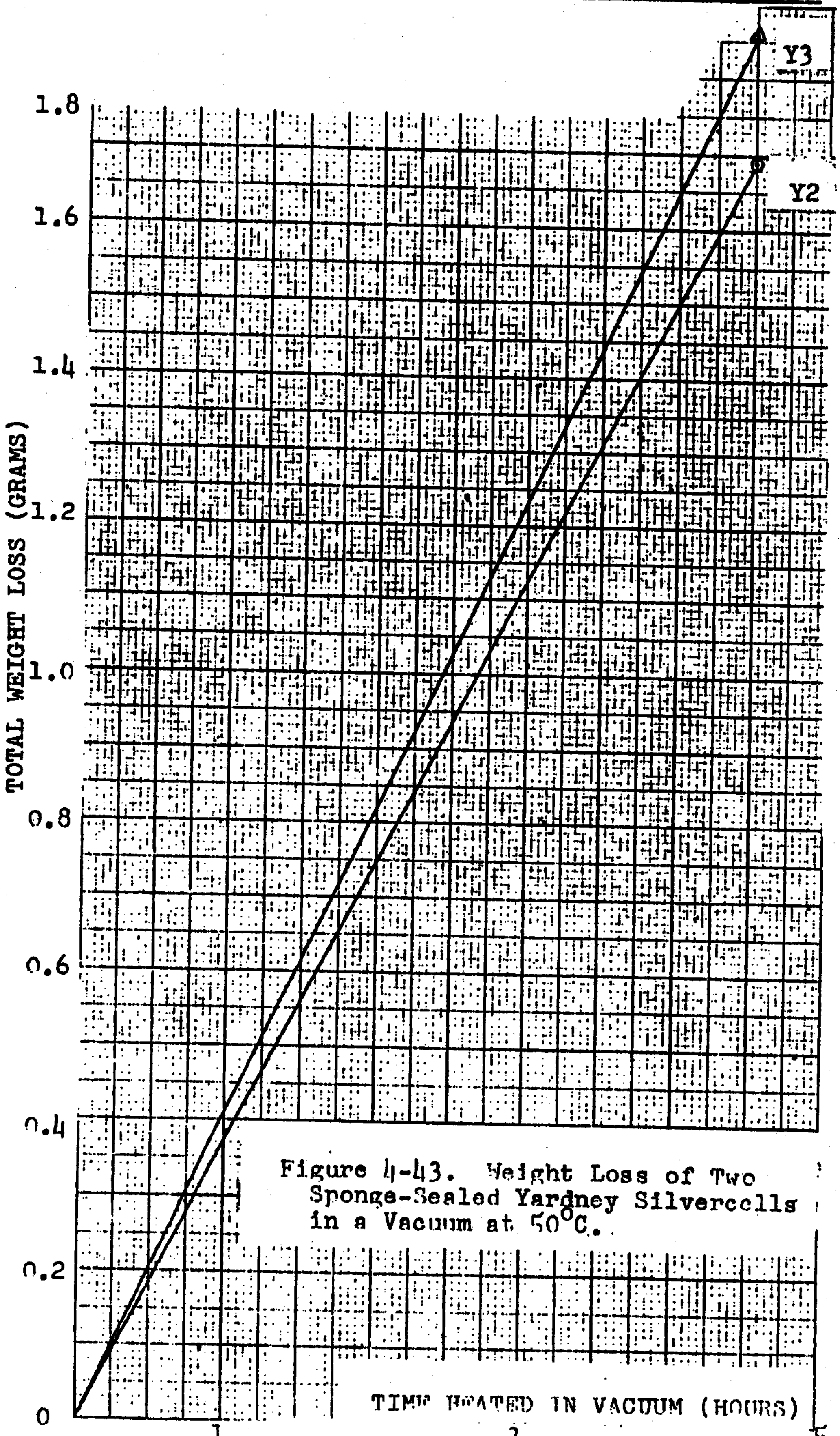


Figure 4-43. Weight Loss of Two Sponge-Sealed Yardney Silvercells in a Vacuum at 50°C.

Front Row (left to right, Figure 4-44)
Gould Button type 32B,
Gould Button type 23B,
DEAC 90 DK,
DEAC 120 DK,
DEAC 150 DK,
DEAC 60 DK

Rear Row (left to right, Figure 4-44)
Yardney Model LR5,
Saft Sealed type VO-4,
Mallory type RM-42R,
RCA,
DEAC 450 D,
DEAC 220 D

The d-c output voltage of each cell, with its load connected and while being subjected to the conditions of vibration, was monitored throughout the five-hour period of vibration by means of Weston type 931 meters.

In addition, a d-c oscilloscope was used on each cell during one complete sweep of the vibration frequency range (8 to 2000 cps) to determine any possible effects on the cell voltage output due to possible cell resonances. Graphic presentations of the recorded data are attached for each of the 60 cells and are self-explanatory.

2. Test Equipment for Vibration Tests

a. Vibration and Monitoring Equipment. The exciter used for the vibration test of the 60 cells was the Calidyne B-44 with a rated force output of 600 pounds vector. (See Figure 4-45.)

The exciter is equipped with a signal generator giving a voltage proportional to the exciter table velocity. The output from the signal generator is fed to two signal monitors mounted

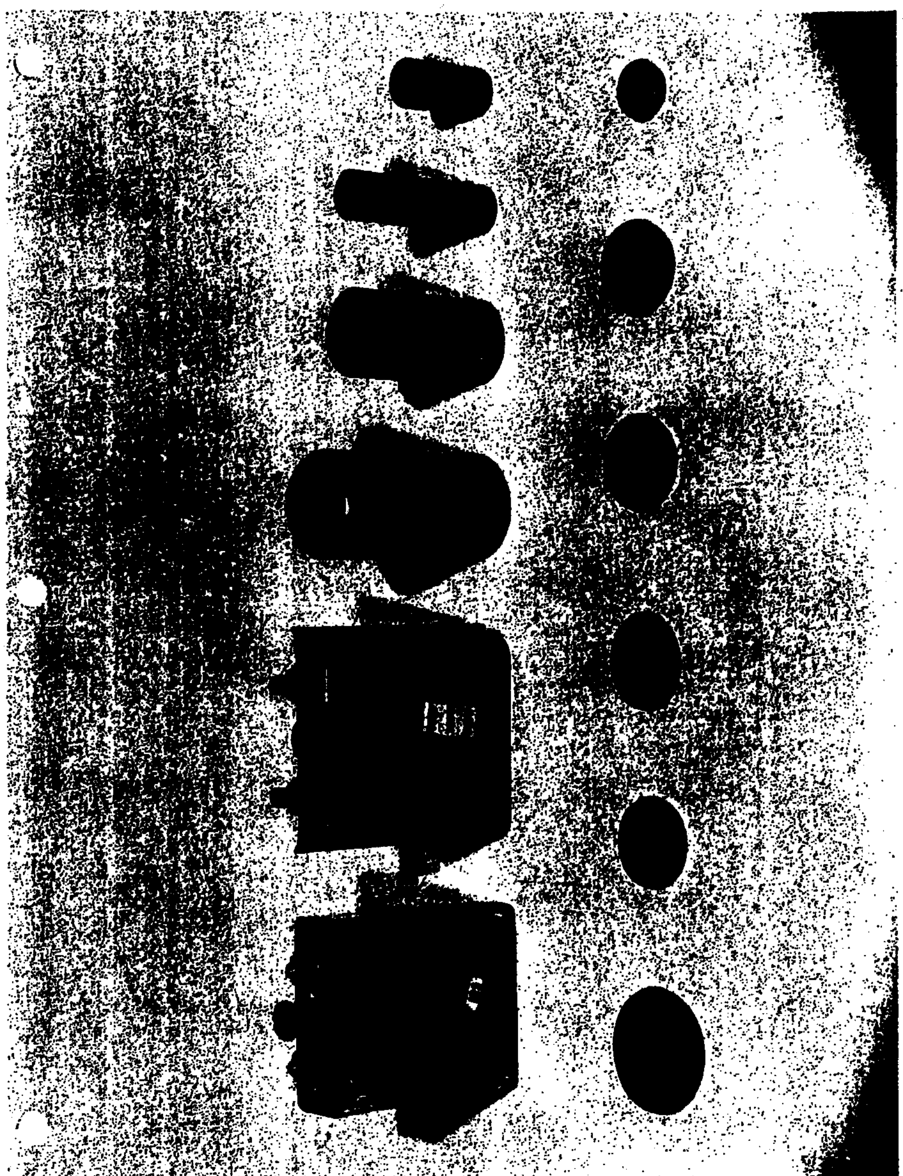


Figure 4-44. Types of Cells Tested for Effects of Vibration.

Figure 4-45. Calidyne Vibrating Equipment with Jigs Mounted on Vibrating Fixtures.

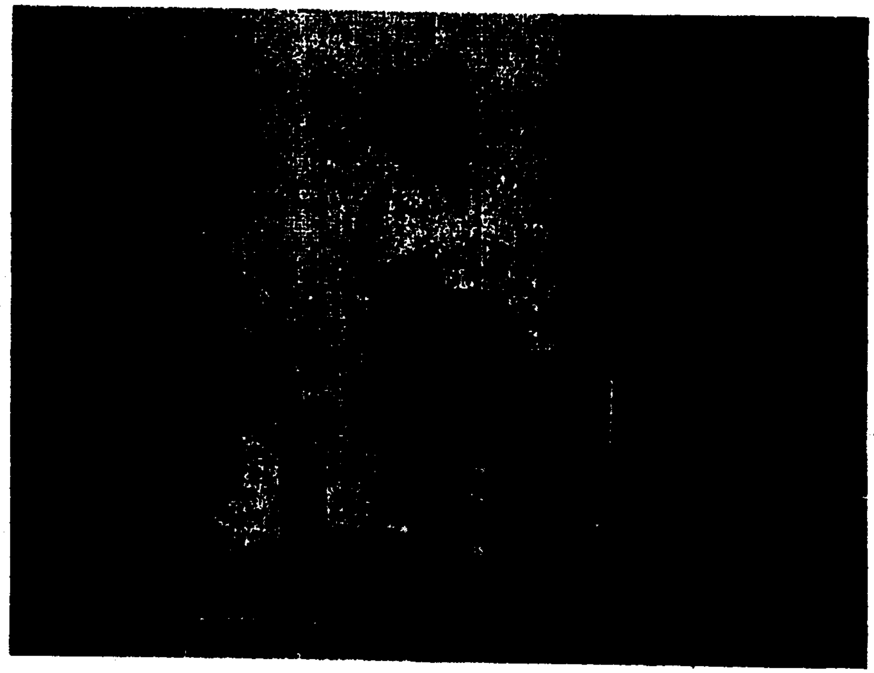


Figure 4-46. Glenite Amplifier, DuMont Dual-Beam Cathode-Ray Oscillograph, and Voltmeter for Monitoring Battery Output During Test.

on the control panel. The signal voltage is integrated or differentiated to produce displacement or acceleration readings on a output meter. Displacement readings are given in peak-to-peak inches and acceleration readings in vector-g's.

The signals from the monitors are fed to a crossover servo control system which, in connection with a frequency sweep cycler, programs the test. In this procedure, the element under test is held at a predetermined displacement level over a portion of the frequency range; after "crossover" it is held at a constant acceleration level for the remaining portion of the frequency range.

Besides the above mentioned monitoring system a direct monitoring of the acceleration of the fixture containing the cells was performed. Two Glenite pickups were fastened to the fixture, one in the direction of the exciter travel and one in a plane perpendicular thereto (in the direction of largest lateral deflection). The signals from the pickups were fed via cathode followers to two channels of a Glenite F406-6 amplifier. The amplifier output was applied to a DuMont dual-beam cathode-ray oscillograph. This monitoring system was calibrated to one inch equals 10g's on the scope. (See Figure 4-46.)

b. Fixtures. (See Figure 4-47.) On the table of the exciter was mounted a symmetrical aluminum jig designed for this test. On the jig was mounted the fixtures containing the cells. All the fixtures used were specially designed. Each fixture was made from "phenolic" and designed in such a manner that the cells were held within the fixture without undue strain on the cell and fixture. The construction of the fixtures consisted of wafers of phenolic of varying thickness with cutouts for the cells. The outermost wafers had a thickness of 5/8 inch and contained either holes for the electrical connections or tapped holes for the contact screws. The capacity of the fixture varied from three for the cylindrical and button type cells to one for

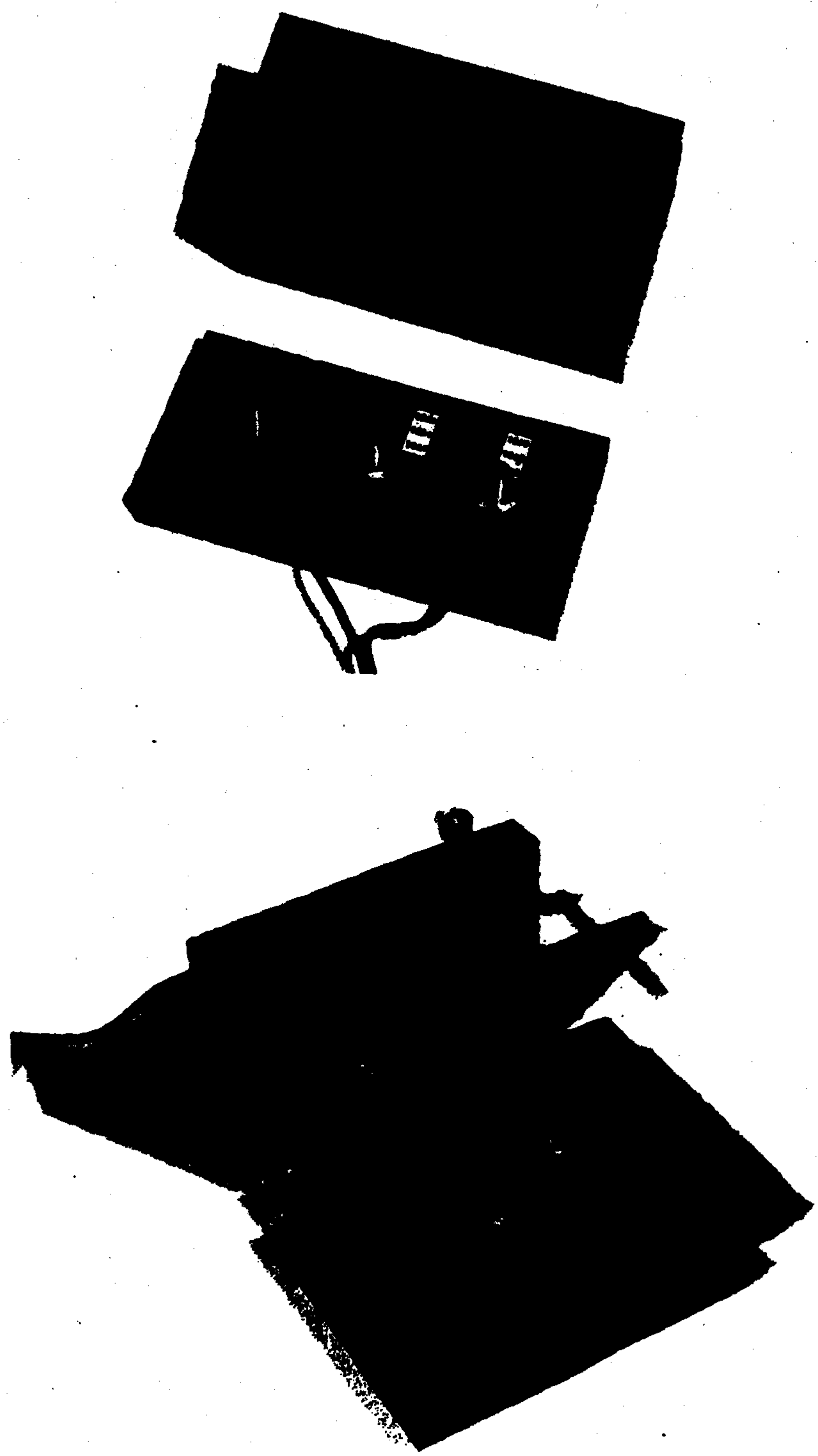


Figure 4-47. Jigs Used to Mount Batteries During Vibration.

the box-shaped cells. The brass contact screws were fitted with a leaf type U-shaped spring made from phosphor bronze. Each fixture was fastened to the aluminum jig by means of 6-1/4-20 steel bolts. Further, the fixtures had tapped holes for mounting the Glenite pickups.

3. Factors to be Considered

a. Load Resistors. It was decided to use load resistors that would discharge the batteries in approximately five hours. In the case of the RCA cell, however, the large current drain required for a five-hour discharge would have reduced the load voltage to a negligible value almost immediately even under an optimum environment. Thus, it was planned to discharge the RCA cells in 100 hours. In the case of the Yardney cells, an error in the calculations resulted in the use of a half-hour discharge load resistor.

b. Testing Discontinuities. Due to operational difficulties with the vibration equipment, the five hours of vibration on each of the cells was not always obtained without interruption. During each such interruption the voltaic cell resistive loads were disconnected so that the five hours of discharge and vibration coincided.

The complexity of the equipment and the limited time allotted for reruns on occasion made it impossible to record the vibration frequency simultaneous with the recording of the battery output voltage.

4. Testing Procedure

During the entire test the exciter was used in a horizontal position in order to eliminate the static deflection of the spring-supported armature. The total maximum weight of the jig, cells, fixtures, fasteners, dummy loads, and exciter table did not exceed 47.2 pounds or at 100g's a vector force of 472 pounds, well within the capacity of the exciter.

Dummy loads were used to bring the combined center of gravity of all vibrated parts to coincide with the centerline of the exciter. This was done so that lateral motion of the vibrated parts is kept at a minimum.

Twelve different types of cells were subjected to vibration. For each type five cells were vibrated in two perpendicular directions. All cylindrical and button type cells were vibrated as follows:

1) Three cells in the direction of the axis of the cylinder.
2) Two cells in the radial direction.

The box-shaped cell types were vibrated as follows:

1) Three cells in the direction of the smallest dimension.
2) Two cells in the direction of the largest dimension.

The same fixture was used for vibration of one particular type of cell in the two different planes of vibration. This was accomplished by mounting the fixture on either of the two planes of the job.

During vibration the fixtures themselves were monitored by attaching Glenite pickups to them. The mechanical amplification or attenuation of the induced acceleration of the jig-fixture system could then be observed. Further, this extra monitoring system acted as a trouble-shooting device enabling the operating technician to detect any looseness in the system before any damage to the equipment could occur.

The maximum displacement of the B-44 exciter table was given by the manufacturer as 0.36 inch peak-to-peak when used with the power pack supplied with the exciter. As the exciter itself is built for a total peak-to-peak excursion of 1 inch it was found desirable to increase the excursion beyond the existing 0.36 inch.

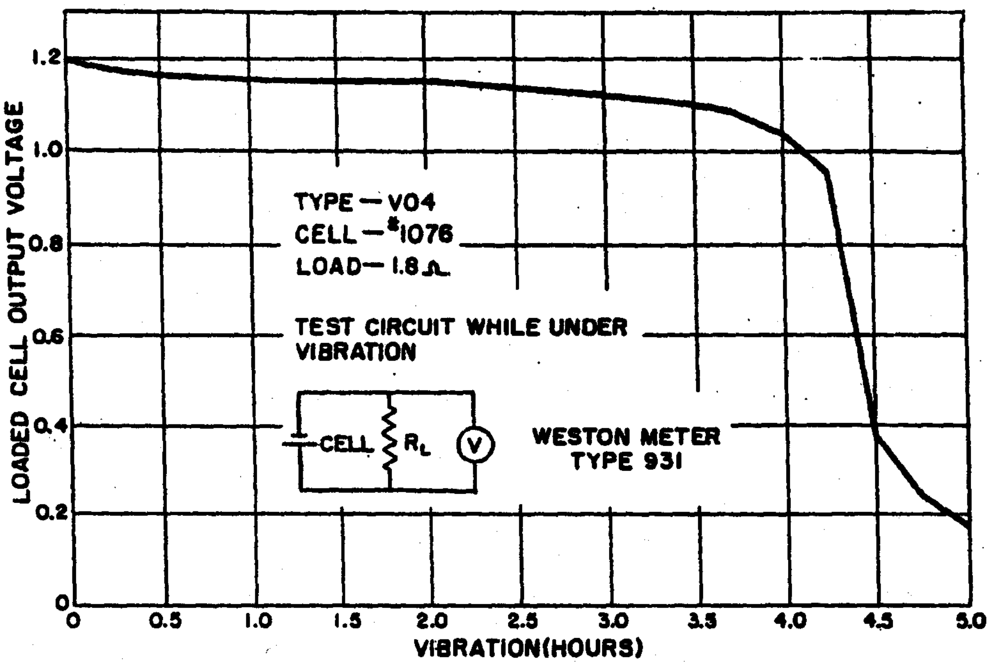
A "Low Voltage Booster" was procured from Calidyne for this purpose and wired into the armature circuit. This booster increased the peak-to-peak excursion to 0.65 inch in the range from 8 to 10 cps, and generally increased the performance of the exciter considerably in the range 8 to 18 cps. Beyond 18 cps, the booster acted as a attenuator and was, therefore, switched out.

The cells under test were subjected to the following vibration (see attached graph):

1) From 8 to 10 cps at a displacement of 0.65 inch peak-to-peak in 5 minutes.
2) From 10 to 40 cps at maximum capacity of exciter (see graph) in 1 to 2 minutes.
3) From 40 to 2000 cps at 10g's in 15 to 18 minutes.
4) No. (3) above in reverse.
5) No. (2) above in reverse.
6) From 10 to 8 cps at a displacement of 0.65 inch peak-to-peak in 2 minutes.

One complete cycling thus lasted from 39 to 47 minutes. The effective vibration time for each cell which varied from 92 to 70 o/o represents the effective vibration time on the first and second run and the 30 o/o "lost vibration" is due to switching time and the miscellaneous exciter breakdowns and power failures.

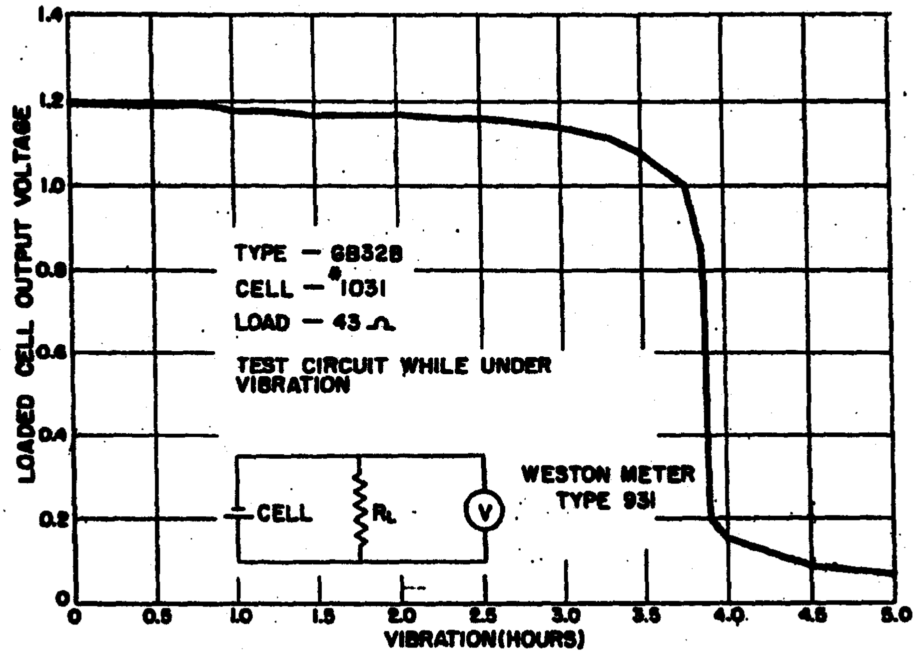
It was found by monitoring the fixtures that accelerations in the direction of excitation differed from the input acceleration. Usually a magnification took place in certain parts of the frequency spectrum. Occasionally attenuation took place but never below 5g's at frequencies above 40 cps. As these phenomena were highly transient a recording thereof was not possible. In one instance, at a frequency of 1900 cps a reading could be taken due to its relatively long period. This reading showed a fixture acceleration of 55g's.



VIBRATION TEST DATA

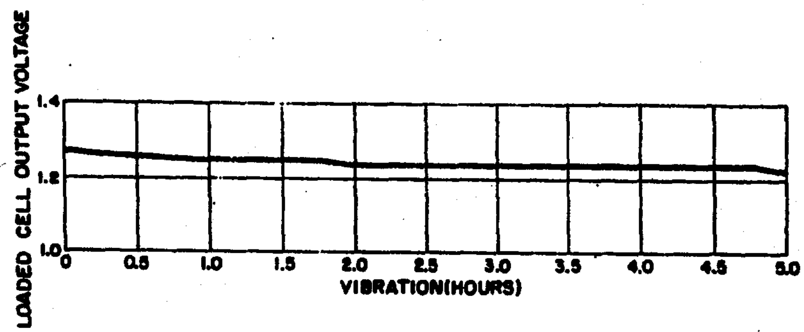
MEASUREMENT TIME HRS.	SAFT SEALED TYPE VO-4 CELL NUMBER				
	1075	1076	1077	1078	1079
0.00	1.19	1.19	1.17	1.19	1.16
0.25	1.18	1.17	1.15	1.17	1.16
0.50	1.17	1.16	1.15	1.18	1.15
0.75	1.17	1.16	1.14	1.17	1.15
1.00	1.17	1.15	1.14	1.17	1.15
1.25	1.17	1.15	1.14	1.16	1.15
1.50	1.17	1.15	1.13	1.15	1.15
1.75	1.17	1.15	1.13	1.15	1.15
2.00	1.17	1.15	1.12	1.14	1.15
2.25	1.17	1.14	1.12	1.14	1.15
2.50	1.17	1.13	1.11	1.13	1.15
2.75	1.17	1.12	1.10	1.12	1.15
3.00	1.16	1.12	1.09	1.11	1.14
3.25	1.16	1.11	1.08	1.10	1.14
3.50	1.16	1.10	1.05	1.08	1.13
3.75	1.15	1.08	0.95	1.10	1.13
4.00	1.15	1.03	0.22	0.26	1.12
4.25	1.15	0.95	0.15	0.19	1.12
4.50	1.14	0.38	0.12	0.15	1.11
4.75	1.13	0.23	0.10	0.12	1.10
5.00	1.13	0.17	0.08	0.10	1.05

Figure 4-48. Vibration Test Data, Saft Sealed Type VO-4.



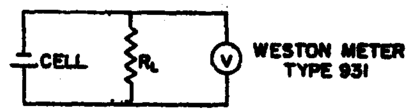
VIBRATION TEST DATA					
MEASUREMENT TIME HOURS.	GOULD BUTTON TYPE 32B				
	CELL NUMBER				
	1030	1031	1032	1033	1034
0.00	1.23	1.20	1.27	1.24	1.25
0.25	1.21	1.19	1.22	1.21	1.22
0.50	1.21	1.19	1.21	1.21	1.21
0.75	1.21	1.19	1.21	1.20	1.20
1.00	1.19	1.18	1.20	1.19	1.20
1.25	1.19	1.18	1.19	1.17	1.19
1.50	1.18	1.17	1.18	1.17	1.19
1.75	1.16	1.17	1.17	1.17	1.19
2.00	1.13	1.17	1.15	1.13	1.19
2.25	0.14	1.16	1.12	0.94	1.18
2.50	0.13	1.16	1.12	0.07	1.17
2.75	0.11	1.15	1.08	0.05	1.16
3.00	0.09	1.14	1.06	0.02	1.15
3.25	0.08	1.12	0.14	0.01	0.13
3.50	0.06	1.08	0.07	0.02	0.08
3.75	0.05	1.00	0.06	0.02	0.06
4.00	0.05	0.15	0.06	0.02	0.05
4.25	0.05	0.12	0.05	0.05	0.05
4.50	0.04	0.09	0.04	0.05	0.05
4.75	0.03	0.08	0.03	0.05	0.05
5.00	0.03	0.07	0.03	0.05	0.05

Figure 4-49. Vibration Test Data, Gould Button Type 32B.



TYPE — G823B
CELL — #1028
LOAD — 91 Ω

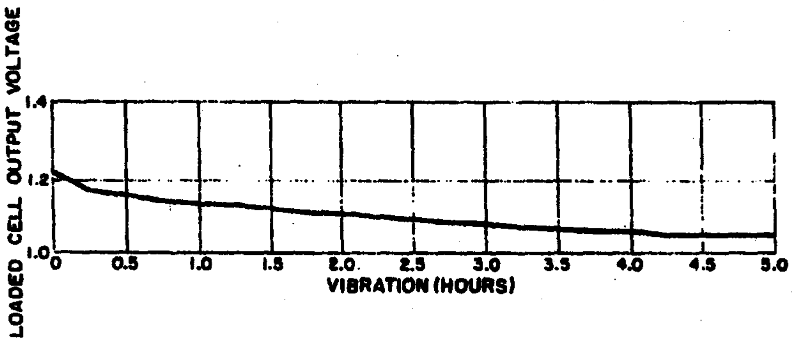
TEST CIRCUIT WHILE UNDER VIBRATION



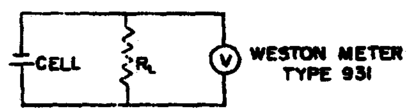
VIBRATION TEST DATA					
MEASUREMENT TIME HRS.	GOULD BUTTON TYPE 23B				
	CELL NUMBER				
	1025	1026	1027	1028	1029
0.00	1.25	1.24	1.08*	1.27	1.27
0.25	1.23	1.23	0.99	1.26	1.21
0.50	1.23	1.23	1.01	1.26	1.21
0.75	1.23	1.24	0.97	1.25	1.21
1.00	1.23	1.24	0.95	1.25	1.21
1.25	1.23	1.24	0.70	1.25	1.21
1.50	1.23	1.24	0.92*	1.25	1.21
1.75	1.22	1.24	1.24	1.25	1.21
2.00	1.22	1.24	1.24	1.24	1.21
2.25	1.22	1.24	1.24	1.24	1.21
2.50	1.22	1.24	1.24	1.24	1.21
2.75	1.22	1.24	1.24	1.24	1.21
3.00	1.22	1.24	1.24	1.24	1.21
3.25	1.21	1.24	1.23	1.24	1.21
3.50	1.21	1.24	1.23	1.24	1.21
3.75	1.21	1.24	1.23	1.24	1.21
4.00	1.20	1.24	1.23	1.24	1.21
4.25	1.20	1.24	1.24	1.24	1.20
4.50	1.20	1.24	1.23	1.24	1.20
4.75	1.20	1.19	1.23	1.24	1.20
5.00	1.20	1.19	1.23	1.23	1.20

*Variations in voltage, from 0.00 to 1.50 hrs. were caused by loose battery connections.

Figure 4-50. Vibration Test Data, Gould Button Type 23B



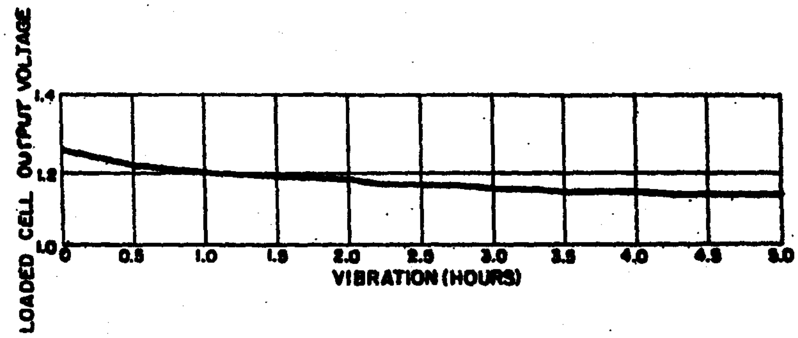
TYPE — DEAC 450D
CELL — 1058
LOAD — 18 Ω
TEST CIRCUIT WHILE UNDER VIBRATION



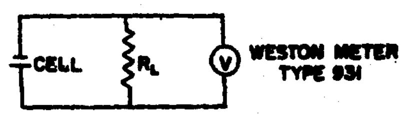
MEASUREMENT TIME HRS.	VIBRATION TEST DATA				
	DEAC 450D				
	CELL NUMBER				
	1055	1056	1057	1058	1059
0.00	1.12	1.18	1.16	1.22	1.18
0.25	1.11	1.16	1.14	1.17	1.15
0.50	1.10	1.15	1.13	1.16	1.13
0.75	1.08	1.14	1.12	1.14	1.12
1.00	1.08	1.14	1.12	1.13	1.11
1.25	1.07	1.13	1.11	1.13	1.10
1.50	1.06	1.13	1.10	1.12	1.09
1.75	1.04	1.13	1.07	1.11	1.09
2.00	1.02	1.12	1.07	1.11	1.08
2.25	1.01	1.11	1.08	1.10	1.07
2.50	1.00	1.10	1.07	1.09	1.07
2.75	0.99	1.10	1.06	1.08	1.07
3.00	0.97	1.10	1.02	1.08	1.06
3.25	0.96	1.10	1.08	1.07	1.05
3.50	0.95	1.07	1.04	1.07	1.05
3.75	0.95	1.07	1.04	1.06	1.04
4.00	0.94	1.07	1.03	1.06	1.03
4.25	0.92	1.06	1.02	1.05	1.02
4.50	0.92	1.06	1,00	1,05	1.02
4.75	0.90	1.06	0.99	1.08	1.01
5.00	0.87	1.05	0.96	1.05	1.00

Figure 4-51. Vibration Test Data, DEAC Type 450D

[redacted]



TYPE — DEAC 220D
CELL — #1085
LOAD — 36 Ω
TEST CIRCUIT WHILE UNDER VIBRATION



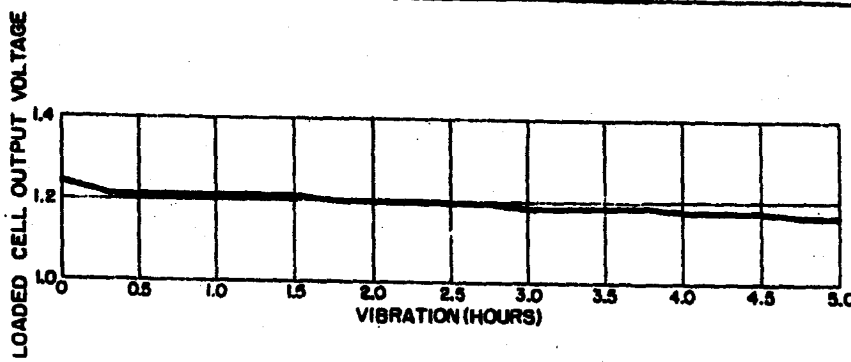
VIBRATION TEST DATA					
MEASUREMENT TIME HRS.	DEAC 220D				
	CELL NUMBER				
	1085	1086	1087	1095	1096
0.00	1.26	1.26	1.24	1.20	1.23
0.25	1.24	1.23	1.21	1.17	1.20
0.50	1.22	1.22	1.19	1.15	1.18
0.75	1.21	1.21	1.18	1.13	1.17
1.00	1.20	1.20	1.17	1.12	1.16
1.25	1.20	1.20	1.16	1.11	1.15
1.50	1.19	1.19	1.16	1.10	1.14
1.75	1.18	1.19	1.15	1.10	1.14
2.00	1.18	1.18	1.15	1.09	1.13
2.25	1.17	1.18	1.14	1.09	1.13
2.50	1.17	1.17	1.14	1.08	1.12
2.75	1.17	1.17	1.13	1.08	1.12
3.00	1.16	1.17	1.13	1.07	1.11
3.25	1.16	1.17	1.13	*1.06/1.11	*1.11/1.17
3.50	1.15	1.16	1.12	1.06	1.12
3.75	1.15	1.16	1.12	1.04	1.11
4.00	1.15	1.16	1.12	1.04	1.11
4.25	1.14	1.15	1.12	1.03	1.09
4.50	1.14	1.15	1.12	1.02	1.08
4.75	1.14	1.15	1.11	1.01	1.07
5.00	1.14	1.15	1.11	1.00	1.06

*Vibration equipment broken down for 127 hours. Batteries were disconnected.

Figure 4-52. Vibra [redacted], DEAC Type 220D

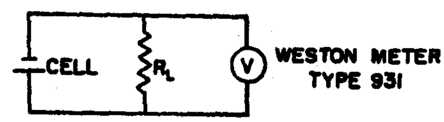
[redacted]

[redacted]



TYPE — DEAC 150 DK
CELL — #1091
LOAD — 50 Ω

TEST CIRCUIT WHILE UNDER VIBRATION

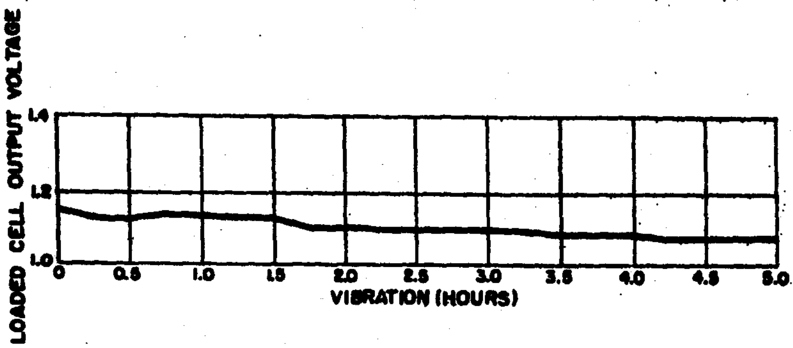


VIBRATION TEST DATA					
MEASUREMENT TIME HRS.	DEAC 150DK				
	CELL NUMBER				
	1081	1080	1090	1091	1092
0.00	1.26	1.24	1.25	1.24	1.27
0.25	1.24	1.23	1.22	1.22	1.23
0.50	1.24	1.22	1.22	1.21	1.23
0.75	1.24	1.22	1.21	1.21	1.22
1.00	1.24	1.22	1.21	1.21	1.21
1.25	1.24	1.22	1.20	1.21	1.21
1.50	1.24	1.22	1.20	1.21	1.21
1.75	1.24	1.22	1.19	1.20	1.20
2.00	1.23	1.22	1.19	1.20	1.20
2.25	1.23	1.22	1.18	1.20	1.19
2.50	1.22	1.21	1.18	1.19	1.19
2.75	1.22	1.21	1.18	1.19	1.19
3.00	1.22	1.21	1.17	1.18	1.18
3.25	1.22/1.25*	1.20/1.20*	1.17	1.18	1.18
3.50	1.21	1.20	1.17	1.18	1.18
3.75	1.20	1.18	1.17	1.18	1.18
4.00	1.20	1.18	1.16	1.17	1.17
4.25	1.20	1.18	1.16	1.17	1.17
4.50	1.20	1.17	1.16	1.17	1.16
4.75	1.19	1.17	1.15	1.16	1.16
5.00	1.18	1.17	1.15	1.16	1.15

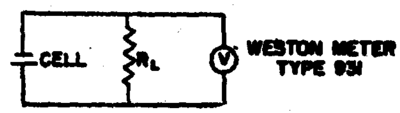
*Vibration broken down. Batteries disconnected for 127 hours.

Figure 4-53. Vibration Test Data, DEAC Type 150 DK

[redacted]

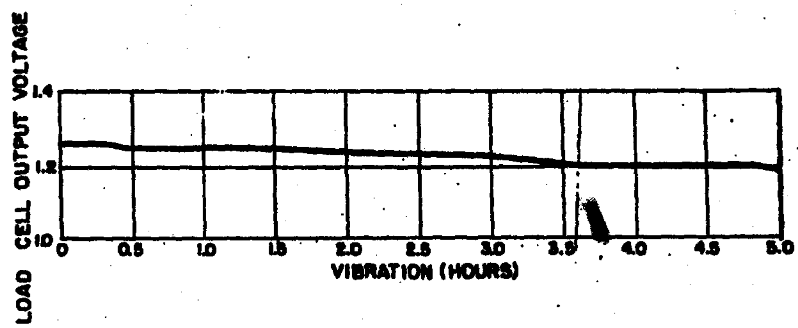


TYPE — DEAC 120DK
CELL — #1042
LOAD — 62 Ω
TEST CIRCUIT WHILE UNDER VIBRATION

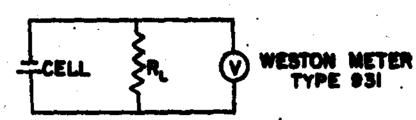


VIBRATION TEST DATA					
MEASUREMENT TIME HRS.	DEAC 120DK				
	CELL NUMBER				
	1040	1041	1042	1043	1044
0.00	1.27	1.26	1.25	1.27	1.26
0.25	1.24	1.24	1.23	1.21	1.24
0.50	1.24	1.24	1.23	1.20	1.24
0.75	1.24	1.25	1.24	1.19	1.24
1.00	1.24	1.24	1.24	1.18	1.23
1.25	1.24	1.24	1.23	1.18	1.23
1.50	1.23	1.23	1.23	1.18	1.23
1.75	1.23	1.23	1.21	1.18	1.23
2.00	1.22	1.22	1.21	1.17	1.22
2.25	1.22	1.22	1.20	1.16	1.21
2.50	1.22	1.22	1.20	1.16	1.20
2.75	1.22	1.22	1.20	1.16	1.20
3.00	1.22	1.22	1.20	1.16	1.20
3.25	1.21	1.21	1.20	1.15	1.19
3.50	1.21	1.21	1.19	1.15	1.18
3.75	1.20	1.21	1.19	1.14	1.18
4.00	1.20	1.20	1.19	1.14	1.18
4.25	1.20	1.20	1.18	1.13	1.18
4.50	1.20	1.20	1.18	1.12	1.17
4.75	1.20	1.20	1.18	1.10	1.17
5.00	1.19	1.19	1.18	0.97	1.16

Figure 4-54. Vibration Test Data, DEAC Type 120 DK

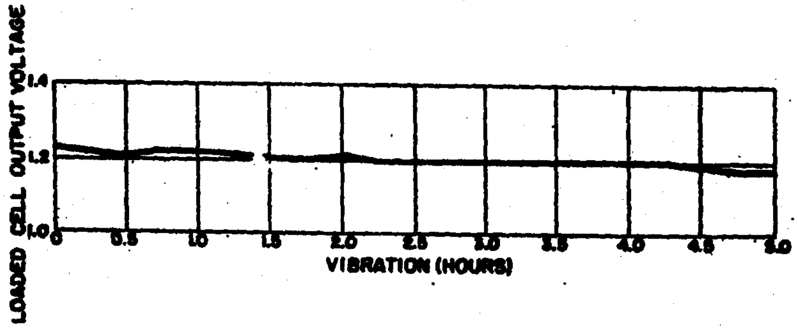


TYPE — DEAC 90DK
CELL — 1047
LOAD — 82 Ω
TEST CIRCUIT WHILE UNDER VIBRATION

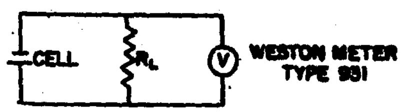


VIBRATION TEST DATA					
MEASUREMENT TIME HRS.	DEAC 90DK				
	CELL NUMBER				
	1045	1046	1047	1048	1049
0.00	1.27	1.26	1.26	1.29	1.27
0.25	1.26	1.26	1.26	1.27	1.25
0.50	1.25	1.25	1.25	1.27	1.24
0.75	1.25	1.25	1.25	1.27	1.24
1.00	1.24	1.25	1.25	1.27	1.24
1.25	1.24	1.25	1.25	1.27	1.24
1.50	1.24	1.25	1.25	1.27	1.23
1.75	1.23	1.25	1.25	1.27	1.23
2.00	1.22	1.25	1.24	1.27	1.23
2.25	1.22	1.25	1.24	1.27	1.22
2.50	1.22	1.24	1.24	1.26	1.22
2.75	1.22	1.24	1.23	1.25	1.21
3.00	1.21	1.23	1.23	1.23	1.21
3.25	1.20	1.23	1.22	1.23	1.20
3.50	1.20	1.22	1.21	1.23	1.20
3.75	1.20	1.22	1.20	1.22	1.19
4.00	1.19	1.21	1.20	1.22	1.19
4.25	1.18	1.21	1.20	1.22	1.19
4.50	1.17	1.20	1.20	1.22	1.18
4.75	1.17	1.20	1.20	1.23	1.18
5.00	1.17	1.20	1.19	1.22	1.18

Figure 4-55. Vibration Test Data, DEAC Type 90DK

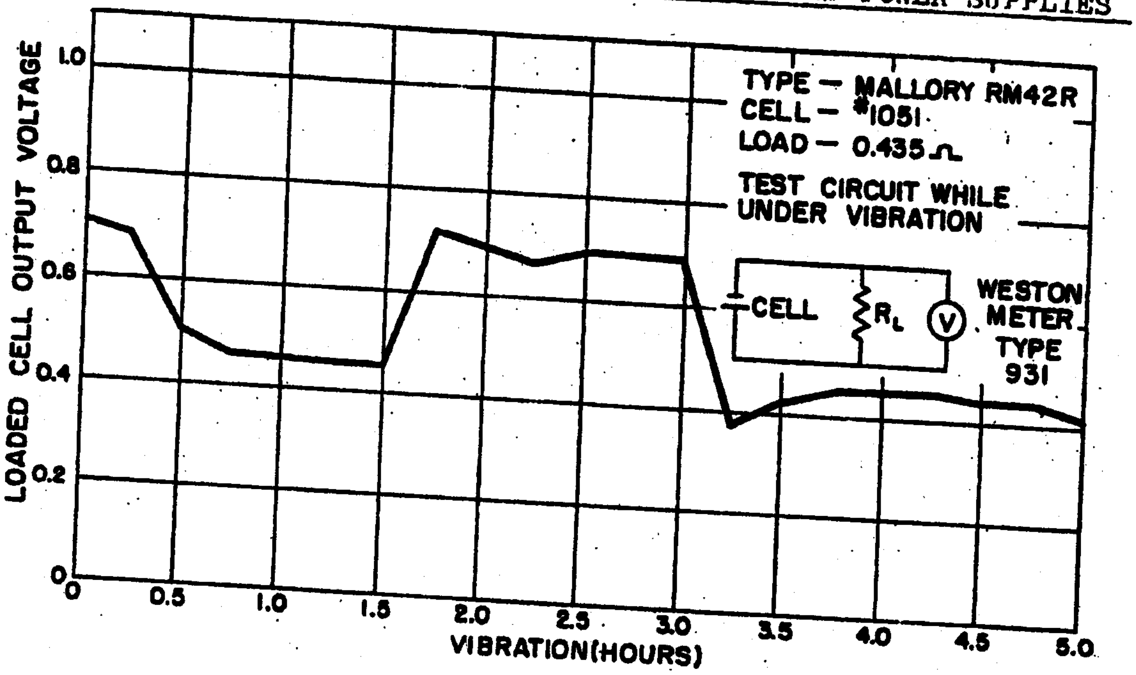


TYPE — DEAC 60 DK
CELL — #1037
LOAD — 124 Ω
TEST CIRCUIT WHILE UNDER VIBRATION



VIBRATION TEST DATA					
MEASUREMENT TIME HRS.	DEAC 60 DK				
	CELL NUMBER				
	1035	1036	1037	1038	1039
0.00	1.29	1.24	1.23	1.26	1.26
0.25	1.25	1.22	1.22	1.24	1.23
0.50	1.25	1.21	1.21	1.24	1.23
0.75	1.24	1.22	1.22	1.22	1.23
1.00	1.24	1.22	1.22	1.22	1.22
1.25	1.23	1.21	1.22	1.21	1.21
1.50	1.23	1.20	1.21	1.21	1.21
1.75	1.23	1.20	1.20	1.19	1.19
2.00	1.21	1.21	1.21	1.14	1.18
2.25	1.21	1.21	1.20	1.18	1.17
2.50	1.21	1.21	1.20	1.18	1.17
2.75	1.21	1.21	1.20	1.18	1.16
3.00	1.21	1.21	1.20	1.17	1.16
3.25	1.20	1.21	1.20	1.16	1.16
3.50	1.20	1.20	1.20	1.15	1.15
3.75	1.20	1.19	1.20	1.15	1.15
4.00	1.19	1.18	1.20	1.15	1.15
4.25	1.19	1.17	1.20	1.14	1.14
4.50	1.19	1.17	1.19	1.14	1.14
4.75	1.19	1.16	1.18	1.14	1.14
5.00	1.19	1.16	1.18	1.14	1.13

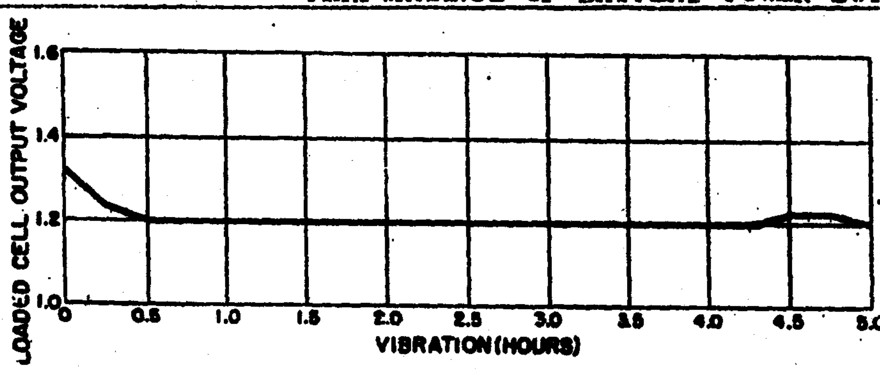
Figure 4-56. Vibration Test Data, DEAC Type 60 DK



VIBRATION TEST DATA

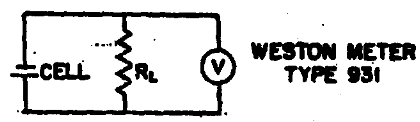
MEASUREMENT TIME HRS.	MALLORY TYPE RM-42R CELL NUMBER				
	1050	1051	1052	1053	1054
0.00	0.51	0.70	0.72	0.78	0.78
0.25	0.45	0.68	0.72	0.70	0.54
0.50	0.45	0.50	0.71	0.48	0.48
0.75	0.44	0.46	0.70	0.43	0.44
1.00	0.44	0.46	0.70	0.43	0.44
1.25	0.44	0.45	0.70	0.43	0.44
1.50	0.44	0.45	0.70	0.44	0.45
1.75	0.46	0.72	0.70	0.44	0.46
2.00	0.46	0.69	0.70	0.45	0.46
2.25	0.46	0.67	0.70	0.45	0.46
2.50	0.44	0.69	0.68	0.48	0.46
2.75	0.44	0.69	0.42	0.76	0.75
3.00	0.68	0.69	0.46	0.74	0.73
3.25	0.65	0.37	0.46	0.71	0.70
3.50	0.43	0.42	0.46	0.69	0.68
3.75	0.47	0.45	0.48	0.67	0.38
4.00	0.47	0.45	0.68	0.34	0.43
4.25	0.47	0.45	0.63	0.35	0.45
4.50	0.65	0.44	0.40	0.45	0.46
4.75	0.55	0.44	0.40	0.43	0.44
5.00	0.40	0.42	0.39	0.44	0.45

Figure 4-57. Vibration Test Data, Mallory Type RM42-R



TYPE — RCA
CELL — #1062
LOAD — 47Ω

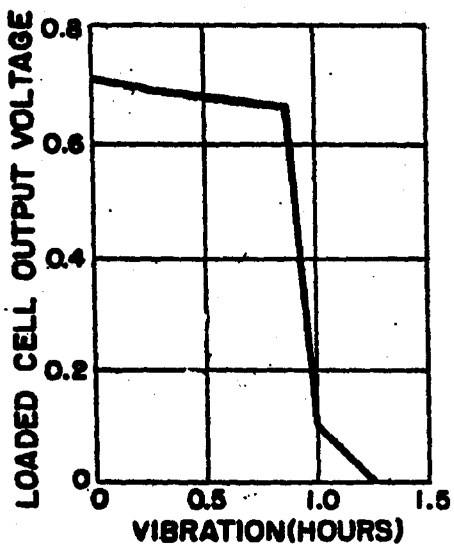
TEST CIRCUIT WHILE UNDER VIBRATION



VIBRATION TEST DATA

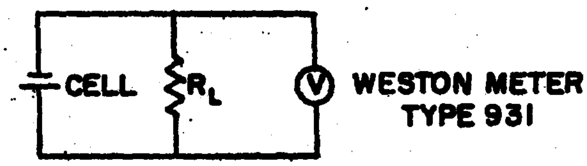
MEASUREMENT TIME HRS.	RCA CELL NUMBER 1060	1061	1062	1063	1064
0.00	1.33	1.32	1.31	0.14	1.59
0.25	1.26	1.23	1.23	0.11	1.33
0.50	1.24	1.22	1.20	0.07	1.23
0.75	1.23	1.22	1.20	0.04	1.21
1.00	1.23	1.22	1.20	0.03	1.21
1.25	1.23	1.22	1.20	0.03	1.21
1.50	1.23	1.22	1.20	0.02	1.21
1.75	1.20	1.22	1.20	0.02	1.21
2.00	1.20	1.21	1.20	0.02	1.21
2.25	1.20	1.19	1.20	0.02	1.21
2.50	1.20	1.18	1.20	0.02	1.21
2.75	1.20	1.18	1.20	0.02	1.22
3.00	1.20	1.18	1.20	0.02	1.22
3.25	1.20	1.18	1.20	0.02	1.22
3.50	1.20	1.18	1.20	0.02	1.22
3.75	1.20	1.18	1.20	0.02	1.22
4.00	1.20	1.18	1.20	0.02	1.22
4.25	1.20	1.18	1.20	0.01	1.22
4.50	1.20	1.18	1.22	0.01	1.22
4.75	1.20	1.18	1.22	0.01	1.22
5.00	1.20	1.18	1.20	0.01	1.22

Figure 4-58. Vibration Test Data, RCA Developmental Cell



TYPE — YARDNEY
CELL — #1067
LOAD — 0.1 Ω

TEST CIRCUIT WHILE UNDER VIBRATION



VIBRATION TEST DATA					
MEASUREMENT TIME HRS.	YARDNEY MODEL LR 5 CELL NUMBER				
	1065	1066	1067	1068	1069
0.00	0.72	0.77	0.71	0.71	0.73
0.25	0.68	0.69	0.69	0.69	0.68
0.50	0.67	0.68	0.68	0.68	0.42
0.75	0.67	0.67	0.67	0.04	0.10
1.00	0.03	0.28	0.11	0.01	0.07
1.25	0.00	0.00	0.00	0.01	0.06
1.50				0.01	0.06
1.75				0.00	0.05
2.00					0.05
2.25					0.04
2.50					0.04
2.75					0.04
3.00					0.04
3.25					0.03
3.50					0.03
3.75					0.03
4.00					0.02
4.25					0.00
4.50					
4.75					
5.00					

Figure 4-59. Vibration Test Data, Yardney Model LR-5

5. Test Results

The vibration test imposed on the cell represents the best that can be achieved with RCA exciters at this time. From the graphs (Figure 4-48 through 4-59) it is apparent that a higher level of vibration would be desirable in the frequency range from 10 to 40 cps.

Severe variations in the discharge characteristics occured on some cells while subjected to the conditions of vibration. The most erratic characteristics observed were those of the Mallory type RM-42R with output voltage variations of more than 50 percent. Some types indicating a large change in the discharge rate, and being discharged prior to the end of the five hours of vibration were the Saft sealed type VO-4, the Gould button type 32-B and one cell of the Deac 120-DK type. The remaining six types of Deac cells, RCA, and Gould button types performed well as indicated on the graphic presentations. In no instance was there any evidence of internal cell resonances detectable with the oscilloscope used for monitoring each cell output voltage during one complete sweep of the vibration frequencies.

F. RECOMMENDATIONS

An increase in the watt-hours per pound figure for the batteries to be used in early ARS vehicles will provide in direct proportion a longer operating time. Development effort should be expended having as its goal an increased figure of watt hours per pound.

Further development to improve the reliability of the seal would probably result in a reduction in the weight of the battery package used in the ARS vehicles. If the cells were sealed to a sufficient degree, a pressurized battery container would not be necessary. Yardney has made some progress in this direction by substituting a pressure relief valve for the sponge type vent.

A thorough study should be made of methods of interconnecting large numbers of cells since the failure of a single connection between batteries might cause the failure of the complete battery package. In general, soldering to individual cells is not satisfactory since the heat required is injurious to the cells. Spot welding of connection tabs to cell components before the cells are assembled might prove satisfactory

Some method of preventing the growth of excess materials on the negative plates of Yardney silvercells should be developed. As the cells are now constructed, this material can form short-circuit paths between plates when carried to the top of the cell by movement of the electrolyte.

A method of preventing the growth of spent chemicals on the exterior of dry cells without increasing their weight is needed. These growths cannot be tolerated where a large number of cells are in close proximity such as will be required in an ARS vehicle. Mercury cells have been greatly improved in this respect but at the cost of adding a separate case around the cell which increases the weight and hence decreases the watt-hours per pound.

Once the final design of the battery package has been completed it should be tested for conformance to electrical, mechanical and thermal requirements prior to the final testing of the complete payload portion of the vehicle.

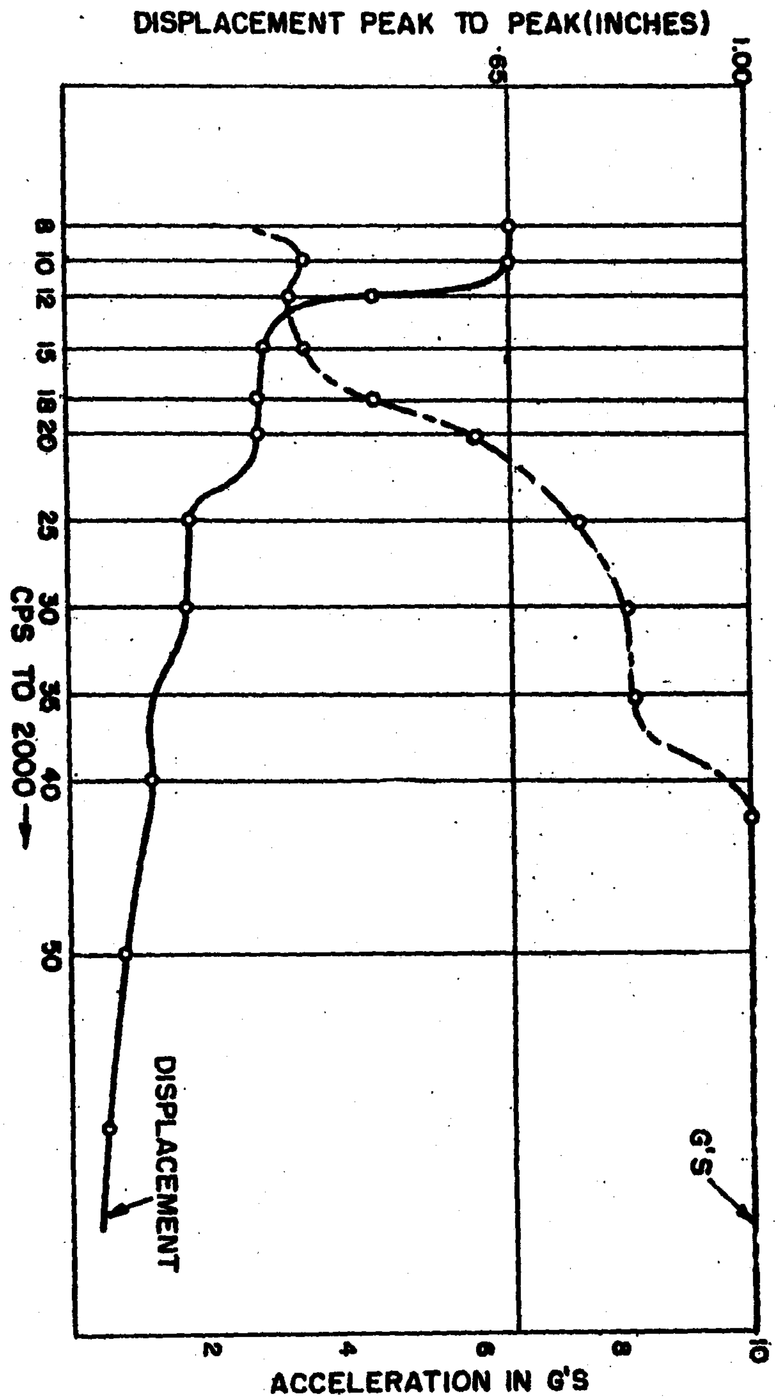


Figure 4-60. Vibration Program

CHAPTER V

PERFORMANCE OF COMPONENTS PECULIAR TO ARS

The ARS will of necessity use components that are not common in military equipment. Some of these components --the electrostatically focused traveling-wave tube is an example -- are still in the development stage. Other components must be modified -- the vidicon target for example -- to meet the specialized requirements of the ARS. Environmental conditions dictate that such routine problems as bearing lubrication be given special consideration. In this chapter various of these specialized problems are considered. In some cases test data were available and have been reported while in others the best information available has been the considered judgement of the people developing the equipment. In many cases it has been possible to indicate in which directions it appears profitable to put forth further development effort and to give in a very rough manner costs and time requirements for these developments.

A. THE VIDICON

1. General

Life and shock tests have been performed on vidicon cameras under contract No. AF33(616)-2576. RCA has also performed test runs on the vidicon temperature sensitivity.[1] It is the purpose of this report to summarize the current data on the vidicon.

1. "Vidicon Temperature Sensitivity", RCA Report EM86C, July 1953.

These tests were performed on the RCA type 6198 vidicon. The camera currently proposed for the first vehicle will require a special vidicon[1] that uses a five-stage electron multiplier and that has a target of larger storage capacity than the standard vidicon. However, the tests made on the standard vidicon will serve as a preliminary guide to determine the feasibility of the tube.

2. Temperature

Using a special temperature compensating circuit to correct for target voltage as a function of temperature, the sensitivity of the vidicon was found to remain constant within ±5 percent over a temperature range of -55°C to 70°C. When the tube is in a non-operating condition (as it will be during launching for example) the vidicon can be subjected to temperatures of 150°C without damage.

3. Shock and Vibration

Vidicons were subjected to the impact shock specified by Mil-E-5272-A. The tube was subjected to 18 impact shocks of 15g, three shocks in each direction for each of three planes. The tube was tested after each shock to determine if any damage was incurred. The impact shock was increased to 55g, the limit of the shock machine, without causing damage to the tube.[2] Actually the vidicon camera should not be subjected to any severe impact shock in the vehicle.

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1. ARS Final Report - June 1956.
2. Martin, "Impact Shock and Vibration Tests of Vidicon (6198) and Image Orthicon (5820)." RCA report EM4216, Nov. 1954.

The vibration to be encountered by the camera in the vehicle might include a range of frequencies from dc to 2000 cycles at a maximum acceleration of 10g.[1] In tests conducted on the vidicon camera, the unit was subjected to vibration over a frequency range of 4 to 500 cycles per second at a maximum acceleration of 7.5g. In these tests the camera was in an operating condition and the picture degradation was observed.

These tests were conducted on the three axes of the camera, namely, the horizontal transverse axis, the vertical transverse axis and the longitudinal axis. Except for a filament failure the tubes tested operated without serious picture degradation to a threshold acceleration for a given frequency. Results of these tests are shown in Table 5-1. The above tests only indicate the limit in viewing a picture during vibration of the camera. Actually the vibration will occur primarily during ascent. During this period the camera will not be operating.

Tests have been run on two vidicons which were vibrated at 2g over a frequency range of 70 cycles to 500 cycles. The tubes were vibrated for a period of one hour at each of eight selected frequencies.[2] No failures were sustained in these tests. However, further evaluation is required for accelerations of 10g and frequencies to 2000 cycles before such cameras can be deemed satisfactory. With proper shock mounting, cameras can be designed to sustain the accelerations which might be encountered.

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1. Note: WDD in a verbal statement to RCA personnel gave these figures based on the ICBM study. Also refer to Oleson, Cunningham, "Rocket Research Report No. XVI Vibration in the Viking 9 Rocket". NRL report 4440, Nov. 1954.

2. Project MX-2226, Report #8, Dec. 1955 to Jan. 1956, RCA Camden, New Jersey.

4. Life Tests

Life tests run on the vidicon for a 4.5 month period of continuous operation showed no appreciable changes in the vidicon.[1] This would indicate a low failure rate per 1000 hours of operation for this tube. Further tests on sampled lots of these tubes should be made to corroborate this assumption.

5. Cost and Availability

Cost and time estimates are currently being prepared in connection with other projects. These estimates can be furnished the Air Force.

B. THE IMAGE ORTHICON

1. General

It has been proposed to use an image orthicon camera in some of the vehicles.[2] Information gathered by these cameras could be recorded on magnetic tape and read out at some later time. The environmental conditions as considered for the vidicon apply to the image orthicon.

2. Temperature

The image orthicon such as the RCA 5820 can operate satisfactorily if the target temperature is maintained between 35 to 45°C. This specification would imply that some temperature control is required for the camera.

The maximum temperature that an image orthicon can be safely subjected to is estimated to be between 85 to 100°C. Tests will be required to determine this upper temperature limit.

1. Op. Cit. footnote #2, page 5-3.
2. Op. Cit. footnote #1, page 5-2.

TABLE 5-1

Threshold of Interference for the Vidicon (6198)

Camera No.	Condition	Frequency (cycles)	Threshold
1	Vibration on axis	48	.015g
		145	.8g
		350	1.5g
2		125	.15g
		305	.25g
		356	.3g
		470	0g
1	Hor. transverse axis	125	.5g
		311	2.5g
		426	.2g
		470	.1g
2		250	.1g
		285	.8g
		480	.2g
1	Ver. transverse axis	85	1.5g
		190	2.5g
		250	.6g
		339	.2g
2		150	2g
		245	.5g
		350	.2g

3. Shock and Vibration

Image orthicons were also subjected to impact shocks similar to the vidicons.[1] The RCA 5820 and 5826 tubes were tested and all withstood shocks to 50g without damage.

Table 5-2 shows the results of vibration tests performed on some image orthicon cameras. These tests are similar to those performed on the vidicon where the cameras were in an operating condition.

Vibration tests were run on two image orthicons over a frequency range of 70 to 500 cycles. These were vibrated at 2g similar to the vidicon test. No failures were recorded[2]. Tests should be conducted for accelerations out to 10g over a frequency range of 0 to 2000 cycles. With proper shock mounting design image orthicon cameras can be designed to meet the anticipated acceleration conditions during ascent.

4. Life Tests

Life tests are currently being conducted on three orthicon cameras.[3] Some of the results of these tests will be summarized. Over a 3000-hour test period it was found that the signal-to-noise ratio of the image orthicon was unimpared where normal full beam modulation of the tube is maintained. Also the target temperature was kept below 45°C.

These tests indicate that the erasure time, i.e. the time required to discharge the signal left on the target after one scan, does not greatly vary over the 3000-hour test period.

1. Op.Cit. footnote #2, page 5-2.
2. Op.Cit. footnote #2, page 5-2.
3. Op.Cit. footnote #2, page 5-3.

TABLE 5-2

Threshold of Interference for the Image Orthicon

Tube No.	Condition	Frequency (cycles)	Threshold
1	Vibration on axis	65	4.5g
		114	5g
		124	5g (Tube failed)
3		65	.8g
		100	.25g
		250	.7g
4	Ver. Transverse axis	125	1g
		157	0.2g
		397	0.175g
4	Hor. transverse axis	65	.17g
		110	.75g
		380	0g

With time the target of the tube will assume progressively lower potentials. In order to continue to obtain a picture it is necessary to increase the target potential voltage. Figure 5-1 shows the averaged rate at which the target voltage should be increased. This was averaged for the three image orthicons tested. A timing device could be used to automatically increase the target voltage as a function of hours of operation.

There is some observed loss of resolution in the image orthicon with time of operation. (See Figure 5-2) This could not be entirely corrected for by readjusting the focus or beam current of the tube. This is a problem requiring further study.

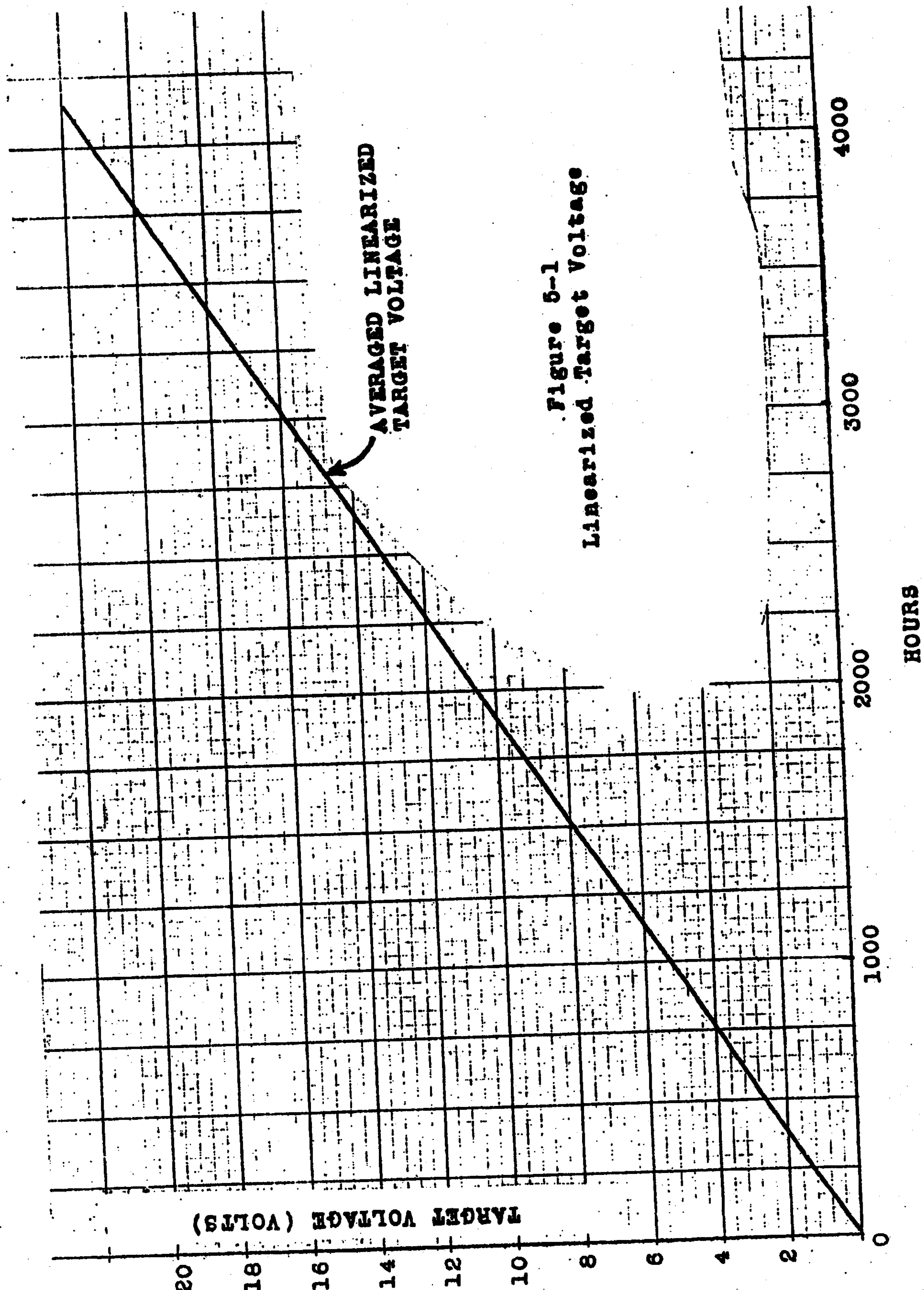

Figure 5-1
Linearized Target Voltage

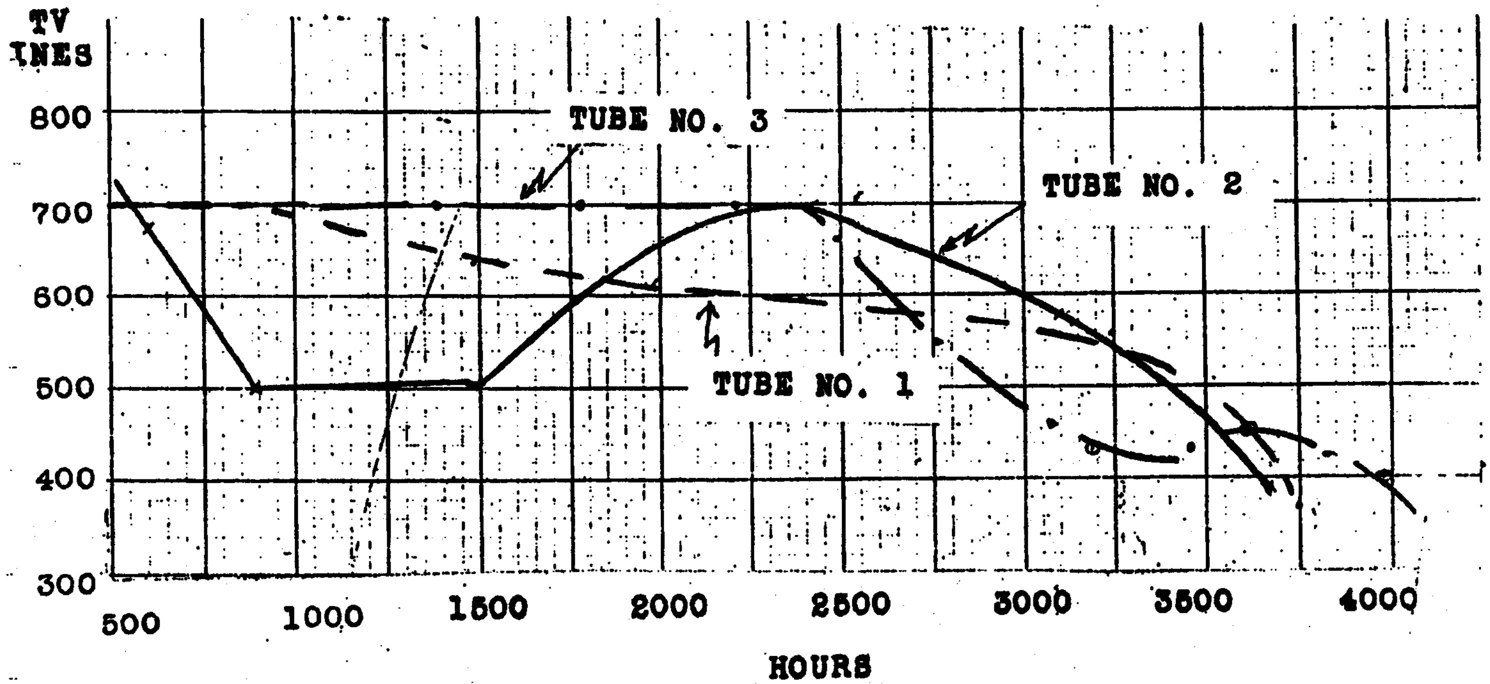

Figure 5-2. Limiting Resolution vs. Time for Three Image Orthicons (RCA 5820)

Also it was observed that the sensitivity (measured as light required to reach the knee) is markedly reduced with time of operation. This could be compensated for by some form of aging.

5. Conclusions

The image orthicons used in these tests were of the commercial type. Thus these tubes can be considered to be available for use in the vehicle.

The most difficult factors facing the design engineer on the use of the image orthicon in a vehicle appear to be the temperature control and the loss of resolution problem. These are not considered to be unsurmountable and continued study should give a satisfactory solution.

C. MICROWAVE TRANSMITTING TUBES

Three types of microwave tubes will probably be required for ARS: (1) beacon transmitter, (2) local oscillator, (3) output tube for the television or ferret transmitter. Before going into the details of these tubes, it is desirable to get an idea of their operating cycle and desired life. For an altitude of 300 miles and an 83° orbit, it is found that the satellite is within line-of-sight range of two U.S. ground stations[1], about one hour per day. For a 58° orbit the corresponding figure is about two hours per day. Assuming that the microwave equipment is always operated whenever it is within range of these stations, a life requirement for one year of satellite operation would be 365 hours for the 83° orbit and 730 hours for the 58° orbit. For a single trip around its orbit the satellite may be in view of the ground stations for a total time varying from zero to a maximum of 9 minutes (83° orbit) or to a maximum of 16 minutes (58°) orbit. It will be off for the remainder of the 90-minute trip. For almost half of its daily trips it will not be in sight of these two ground stations.

1. Beacon Tubes

It is assumed that the vehicle will include a beacon to assist in radar tracking and possibly for use in transmitting telemeter data to the ground. Typical of present-day beacon magnetrons are the types QK-362, QK-299 and BL-212 which are now in production. Two other tubes, the QK-530 and BL-211, are now in an advanced stage of development. These tubes, which will have substantially improved performance and reliability, should be in production in about one year and hence should be useful for the ARS program.

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1. It is assumed that one station is in the northeast part of the U.S. and the other in the northwest.

a. QK-362. The QK-362 is a tunable X-band tube (9300 to 9500 mc), with a power output of 60 watts peak, duty factor of 0.002, and anode voltage of 1200 to 1500 volts. An intermittent life test is specified in which (a) the heater voltage is applied for 45 seconds, (b) heater plus anode voltage for 5 minutes, (c) no voltage for 5 minutes, then repeat for a mimimum of 3000 cycles. This corresponds to a total "on" time for anode voltage of 250 hours. However, it is understood that actual operating times (using the above cycle) of 1000 to 1500 hours are obtained with this tube, during which time the output power stays constant within about 1 db. Mechanical specifications include vibration of 10 to 60 cps at 0.08-inch total excursion, and 60 to 2000 cps at a constant acceleration of 15g in each of three mutally perpendicular planes. This test calls for 15 minutes operation in each plane during which time the magnetron spectrum is examined and required to remain within specified limits. A 500g centrifuge test is included wherein maximum acceleration is reached in one minute, maintained for one minute, and decreased to zero in one minute. Spectrum and absolute frequency limits must be met during this test, Shock tests at 500g for 1 millisecond in a plane parallel to the major axis (cathode) and at 250g in a normal plane are also included. The tube is not required to meet operating specifications during the shock tests but it must meet all specifications after these tests. The tube must also withstand a 300-rpm spin about its main axis without shifting frequency more than ±1.25 mc, and maintain its spectrum within limits.

b. QK-299. The QK-299 is a higher powered tunable X-band beacon magnetron with an output of 800 watts peak and an operating voltage of 4 to 4.5 kilovolts. The life test cycle consists of (a) application of heater voltage for 25 seconds (b) heater plus anode voltage for 30 minutes, (c) no voltage for 5 minutes, then repeat for a minimum of 1000 cycles (500 hours "on" time).

c. BL-212. The BL-212 is tunable C-band tube (5400 to 5900 mc) which has similar specifications to the QK-362 except that its peak power is 100 watts rather than 60.

d. QK-530 and BL-211. The QK-530 and BL-211 are X- and C-band tubes respectively, in an advanced stage of development, which will supersede the QK-362 and BL-212. They are electrically similar to their predecessors, but differ in the environmental specifications, in the life test specification, and in the testing procedure. They must withstand 20,000g spin at 13,500 rpm and shocks of 1000g and 500g parallel to and normal to the plane of the cathode. The life test spec has also been increased to 1000 hours rather than 250 hours. In the proposed production of these tubes, it is planned to build 300 and apply all of the electrical tests to these. In addition, x-rays of every part for every tube are made prior to assembly, and then an x-ray is taken after assembly. Thirty-two of the 300 tubes are randomly selected and subjected to the environmental tests. If any two of this lot fail the entire 300 tubes are rejected. These two tube types which should be in production in about 1 year should result in high performance and high reliability units.

2. Local Oscillator Tubes

There are in the 3000-to-10,000-mc band a number of reflex klystron local oscillator tubes which are descendants of the World War II type 723 A/B. These include, among others, the 2K25, 2K26, and 2K56. They have been in use for a number of years and a fair amount of life data are available.

One microwave link (4000 mc region) comprising about 24 stations (and twice this number of equipments), has been in operation about 8 years on a continuous 24-hour per day basis. The average life obtained with 2K56 tubes on this link has been over 10,000 hours and some tubes have gone 25,000 hours.

Other microwave links in the 6000-mc region have reported figures of over 10,000 hours average life for the 5976, which is in the same family as the tubes mentioned above.

The 416-B, a small triode used at 4000 mc, is reported to average over 10,000 hours in a large microwave link system employing hundreds of these tubes.

3. Transmitter Tubes

It is assumed that from 0.1 watt to 10 watts will be needed to transmit the ferret or television reconnaissance data back to the ground, depending on the required bandwidth, antenna size, and receiver noise figure. For microwave tubes having outputs of about 0.1 watt, some of the local oscillator types mentioned above can be used. For tubes with an output of 1 watt, there is available the SRC-43 family of tubes made by Sperry which cover the 5925 to 8100 mc range. Similarly, Varian have their VA-220 series from 5925 to 7425 mc, with the same power output. Both of these tubes have a 2000-hour guarantee, but the manufacturers clain that they are designed for 10,000-hour operation and field usage in microwave links confirms this. The VA-222 has the same characteristics as the VA-220 except that is is designed for conduction cooling, rather than forced air cooling. A suitable heat sink must be used in order to keep tube body temperature at the desired level.

One manufacturer states that life expectancy cannot be predicted from a "run-in" period of 500 to 1000 hours. The characteristics of these tubes change very slowly during life until the last one or two thousand hours. A "run-in" period of a few hundred hours should catch the small percentage of tubes which have a catastrophic failure. The life expectancy will be increased if operating temperature is reduced. The recommended tube body temperature is below 100°C, and for emphasis on reliability a much lower temperature is desirable.

It is pointed out that tubes operated in microwave links are run continuously, except for repair or maintenance shutdowns. In the ARS application the tubes will be operated in an on-off cycle and it might be expected that these transients might shorten cathode life. The life of a given tube under cycled conditions cannot be simply extrapolated from a knowledge of its life under constant conditions. Because of the many variables it is necessary to run a given tube under the desired conditions in order to find what its life is. Some data are available from a test performed by Sperry on four of their SRC-43 klystrons (which normally run about 10,000 hours). These tubes had heater and beam voltages applied simultaneously for one minute, then both were removed for four minutes; this cycle being continued for 85,000 times, or a total "on" time of 1415 hours. At the end of this time there was no indication of deterioration of emission in these tubes. The test was stopped here. The important factor for the ARS program is that tube life was well over the 400 to 800 hours needed in the ARS project.

For tubes with a higher power level, say 5 to 10 watts, several different types are available (see Table 5-3) including multicavity klystrons, klystron amplifiers, traveling wave amplifiers, and magnetrons. Reflex klystron oscillators are rather difficult to make at this power level for the frequency range 4 to 10 Kmc, although a family of 5-watt reflex klystrons is available in the 2-Kmc region (SRL-7 made by Sperry). The tubes listed at the 5 to 10 watt level are all in various stages of development. This almost automatically makes life data questionable, except where the tube uses a cathode which has been previously proved out in another production tube.

The efficiency figure given in Table 5-3 is that of actual power output divided by d-c power input. It would be more correct to use an overall efficiency which would include the power required by the oscillator tube, if one is evaluating amplifier efficiency. The weight figure must be combined with the weight of its related circuitry for the most meaningful figure. Some of the tubes shown include integral cavities, while others require external cavities. Power supply stability requirements and operating voltages will affect the weight of the power supply required. For example, the X-563E klystron amplifier tube weighs 3 pounds but the amplifier package (including cavity, focusing coils, blowers, and frame) weighs 27 pounds. Power supply weight is not included. Because of these considerations, relative weight and efficiency figures must be used with caution.

It is believed practical to use a traveling-wave amplifier as an oscillator, by coupling the input and output through a resonant cavity. Further, frequency modulation can be obtained by modulating the helix voltage. By using the tube in this fashion, rather than as an amplifier, one can eliminate an oscillator stage. The A-120 tube uses a Pierce type cathode which should have good life, because of its relatively large area, but actual data are not yet available for this particular tube.

The use of a focusing solenoid with the traveling-wave tube is not recommended because of the power required (several hundred watts), the forced-air cooling needed, and the resultant weight of this package. A permanent magnet, periodic focusing structure has been developed which replaces the solenoid and thereby makes the traveling-wave tube an attractive possibility. On the ground some forced-air cooling would still be required for collector cooling. Forced-air cooling in the satellite would require a pressurized case, which is not desirable. It may be possible to design a suitable heat sink so that air cooling could be eliminated.

The A-1061 magnetron, with its low operating voltage and high efficiency, has been the most promising tube for the ARS application. However, it would be desirable to extend its life beyond the average of 600 hours now being attained. The use of a cathode similar to that used in RCA's C-band weather radar magnetron should be an improvement in this respect.

4. Conclusions

To sum up, it appears that life expectancy required for this application for beacon, local oscillator, and lower powered transmitter use (0.1 to 1 watt), can be met with existing tubes now in production. For higher powered tubes, 5 to 10 watts, this is not the case. Where efficiency is of prime importance a modification of the A-1061 FM magnetron may be the most promising development. For a longer range program, a traveling-wave tube may eventually provide a more reliable answer to the problem.

D. TRAVELING-WAVE TUBES

1. Introduction

A scanning superheterodyne and a crystal video receiver with traveling-wave tube preamplifier have been tentatively proposed[1] for the ferret receiver. This section will discuss traveling-wave tube (TWT) performance requirements and reliability considerations in connection with the latter design. A development program which may make the TWT competitive and possibly superior to the scanning superheterodyne solution is discussed.

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1. RCA and Bell Aircraft Report "Development plan for an Advanced (Satellite) Reconnaissance System for United States Air Force" Feb. 29, 1956 - Contract AF33(616)-3104 pp. 2-48 to 2-52.

Tube	Z-5098	A-1061	---	---	X-563E
Type	voltage tuned magnetron	FM magnetron	multiple reflection klystron	traveling wave ampl.	klystron amplifiers
Mfgr.	G.E.	RCA	Phillips - Holland	F.T.L.	Eimac
Freq. -mc.	2700-3300	6500	8800	X band	5900-6400
Power output-watts	4	5 to 7	10	10	55
Efficiency percent	12	20	20	15	18
High Voltage required-volts	1100	580 to 650	2500 anode -1100 refl.	---	2750
Life-hours	?	500 to 1000	1000	expect several thousand	?
Cooling	forced air	conduction	not known	forced air	forced air
gain-db	---	---	---	25-35	30
				requires 500 watt electro-magnet	requires 338 watts in focusing coils

TABLE 5-3

Tube	416B	VA-222 VA-1	DX-122	DX-123	SAC-45
Type	triode	reflex klystron	2 cavity klystron osc.	2 cavity klystron osc.	klystron amplifier
Mfgr.	Western Elec.	Varian	Amperex	Amperex	Sperry
Freq. -mc.	up to approx. 5000	5 types cover 5925 to 7425	8,500 to 10,500	8,500 to 10,500	6000
Power output-watts	0.5	1	5	33	10
Efficiency-percent	about 10	2 to 3	5	11	10
High voltage required-volts	250	750 and -375	2750	4350	1000
Life-hours	>10,000	guar. 2000 actual about 10,000	>1000 (no more exact figures available)	>1000 (no more exact figures available)	expect 10,000
Cooling	forced air	conduction	water-1/2g.p.m.	water-1/2 g.p.m.	forced air
Gain-db	about 6 db	---	---	---	25 to 30
Comment		Sperry SRC-43 family, covering 5925 to 8100 mc. (has similar characteristics)			

TABLE 5-3 (continued)

Tube	A-120
Type	Traveling wave ampl.
Mfgr.	RCA
Freq.-mc.	5900 to 7400
Power output-watts	about 8
Efficiency - percent	about 10
High voltage required-volts	2000
Life-hours	expect several thousand
Cooling	forced air
Gain-db	25
Comments	Now uses electro-magnet requiring several hundred watts - permanent periodic magnet structure to be ultimately used, total wt. = 10 lbs.

TABLE 5-3 (continued)

2. Requirements

A listing of the ferret parameters affecting the receiver design (Table 5-4) will serve as a basis for deriving TWT performance requirements.

TABLE 5-4

Ferret Parameters

Minimum Signal Amplitude[2]	-55dbm
Acceptable S/N ratio	15db
Frequency Range [1]	700 to 12,000 megacycles
Maximum channel bandwidth[1]	3000 megacycles
Assumed video bandwidth (0.1 microsecond pulse length)	10 megacycles

If the channel bandwidth were not so wide the TWT noise, for a reasonable noise figure, could be neglected compared to the noise in the crystal video. For the case under consideration, however, the TWT noise is not negligible. Consequently the mimimum gain depends on the maximum noise factor as shown in Table 5-5. The figures therein given represent end-of-life conditions.

TABLE 5-5

Required Gain vs Max Noise Figure for 3000-Mc Bandwidth

Gain db	Noise Factor (db)
23	0
23.5	10
24.1	15
25	17
28.4	20
α	21.5

1. RCA and Bell Aircraft Report "Development Plan for an Advanced (Satellite) Reconnaissance System for United States Air Force" Feb. 29, 1956 - Contract AF33(616)-3104 pp. 2-48 to 2-52
2. RCA and Bell Aircraft Report "Second Quarterly Progress Report, "Advanced Reconnaissance System, Research and Design Study" Contract AF33(616)-3104 p. 111-42 Fig. III-20.

Similar figures for a 2000 mc bandwidth are given in Table 5-6.

TABLE 5-6

Required Gain vs Max Noise Figure for 2000-Mc Bandwidth

Gain db	Noise Factor (db)
23	0
23.3	10
23.9	15
27.0	20
α	22.2

Since ferret does not propose to measure signal intensities, moderate variation in gain across the pass band of the TWT will not be important as long as the gain does not fall below the values listed in Tables 5-5 and 5-6. Difficulties arising because of gain variation with frequency can be readily corrected either by suitable networks in the output of the TWT or by systematically adjusting the thresholding of the crystal video receivers fed by the TWT preamplifier.

Shock and vibration requirements, pertaining only to survival in a non-operating condition, apply to the TWT. The duration of the test period should be based on the time between launching the satellite and its entry into orbit.

The power consumed by the TWT pre-amplifier must be compatible with the ferret power plant capacity. For Ferret 1, which is powered by batteries, only 60 watts has been allotted[1] to the receiver. In Ferret 2 the power plant's average capacity is 250 watts[2]. Assuming that a power storage facility is included and that the operating duty cycle is 10 percent the

1. Refer to footnote #2, page 5-20
2. Refer to footnote #2, page 5-20

peak power available is 2500 watts of which an, as yet, undetermined fraction would be supplied to the receiver. Ferret 3 has an even larger power capability and need not be given consideration.

3. Status of Available TWT's

While the low power, wide band TWT has interesting possibilities for ferret application, considerable development is required before a practical ferret receiver can be constructed using TWT's. Some of the deficiencies of currently available tubes are:

1) The power required (100 to 180 watts per tube) for electromagnetic focusing precludes the use of the TWT in Ferret 1 but not necessarily in Ferrets 2 and 3. However, the large power required for electromagnetic focusing alone puts the TWT receiver at a disadvantage compared to the scanning superheterodyne receiver
2) Present tubes and their focusing coils weigh from 15 to 23 pounds depending on whether the winding is aluminum or copper. The weight of a full complement (five to seven) of TWT's (75 to 160 pounds) puts the TWT receiver at a disadvantage compared to the scanning superheterodyne.
3) Full frequency coverage (700 mc to 1200 mc) is not possible at present. Tubes do not appear to be available in the lower part of this spectrum.
4) Adequate shock and vibration testing has not yet been performed. It is doubtful if present tubes could withstand a realistic test. Some work is being done at RCA's Harrison plant to ruggedize the helix.

The disadvantages of electromagnetic focusing are not inherent in the TWT. The focusing power can be eliminated and the weight substantially reduced by employing periodic magnetic focusing[1] with permanent magnets. This principle has already been used successfully in the developmental power TWT type A1084 by the TWT section of RCA at Harrison. According to these people a low power TWT employing periodic magnetic focusing should weigh no more than 3 to 5 pounds[2]. The permanent magnets would be small enough to be incorporated into the tube structure. If this were done, the manufacturer would supply the tube prefocused. The user would not be required to align the focusing field as he must be in the case of electromagnetically focused tubes.

If electrostatic focusing proves to be practical, weight reduction to less than 1 pound[3] per tube may be in prospect. TWT tubes employing a bifilar helix have been constructed at the RCA Laboratories at Princeton. Focusing is accomplished by a combination of electrostatic and magnetic fields. A magnetic field applied to the cathode region of the TWT focuses the electron stream until it is introduced into the bifilar helix. Beyond this point the electron stream is constrained by electrostatic lenses formed between each turn of the helix by applying the proper d-c voltage between the windings of the helix.

The electrostatic tube, while promising, is still in an early developmental stage. Hence its possibilities as a production tube cannot be estimated with the same assurance as the periodic magnetically focused tube.

1. RCA Review Sept. 1955, Vol XVI, "Periodic Magnetic Focusing for Low Noise TWT" KKN Chang.
2. Does not include the weight of a mounting capable of withstanding shock and vibration.
3. Op. Cit. footnote #2 this page.

To offset the difficulties listed above, the TWT has interesting reliability possibilities assuming it can be ruggedized to withstand shock and vibration. In developing TWT's employing the basic A1038 envelope and helix, the RCA Harrison people have noticed that tubes which passed the 50-hour service mark usually had a life well in excess of 1000 hours. For example four tubes placed on life test early this year had accumulated by June 1, 3000 to 3500 hours service without marked deterioration. By 50 hours the catastrophic failures, principally leakages, have largely occurred. With these failures eliminated, a long life should be expected for the remaining tubes because the oxide coated cathode, the weakest tube element, is run at a very low temperature (750°C) and neither the noise factor nor the gain is critically dependent on cathode emission.

4. Derivation of the Gain and Noise Factor Requirements

The computation of the TWT gain and noise factor requirements proceeds in this manner:

1) Compute the noise level of the crystal video receiver.
2) Compute the noise at the TWT input.
3) Transferring the signal level (-55 dbm or 3.16×10^{9} watts) and item 2 to the crystal video input, combine transferred noise with item 1.
4) Find the relation between gain noise factor to achieve 15 db signal-to-noise ratio at the crystal video input.

From published data[1] the noise level of a 10mc bandwidth crystal video receiver is -47 dbm (2×10^{-8} watts) for a figure of merit of 18. That this figure checks reasonably well with practical crystal video receivers can be shown as follows:

A keying threshold of -40 dbm is easily attained for a 2 mc bandwidth. Referring to the published data, the noise

1. M.I.T. Radiation Lab Series #3 "Radar Beacons" p. 176 Fig. 8-18

level of a 2 mc crystal video receiver is -50 dbm. The difference (10 db) is a reasonable allowance to achieve a workable false alarm time and probability of keying.

The noise at the input to the TWT is at 3000 mc, neglecting video integration due to contracting the video bandwidth to 10 mc: $1.374 \times 10^{-23} \times 300 \times 3000 \times 10^{6}\ NF = 1.24 \times 10^{-11}\ NF$ where NF is the noise factor. Including the effect of contracting the video bandwidth to 10 mc this becomes

$$1.24 \times 10^{-11} NF \times \sqrt{\frac{10}{3000}} = 0.715 \times 10^{-12}\ NF.$$

The noise at the crystal video receiver is the sum of its noise and the amplified TWT noise or

$$0.715 \times 10^{-12}\ NFG + 2 \times 10^{-8} \text{ watts}$$

The signal at the crystal video input is: $3.16 \times 10^{-9} G$.
The requirement that the signal be 1.5 db above noise requires that

$$\frac{3.16 \times 10^{-9} G}{0.715 \times 10^{-12}\ NFG + 2 \times 10^{-8}} = 31.6 \text{ or}$$

$$G = \frac{200}{1 - 0.715 \times 10^{-2} NF} \qquad (1)$$

This relation is tabulated in Table 5-5.

The TWT noise for a 2000 mc bandwidth, neglecting video integration is:

$$2/3 \times 1.24 \times 10^{-11} NF = 0.84 \times 10^{-11} NF$$

Including video integration this becomes

$$0.84 \times 10^{-11} NF \sqrt{\frac{10}{2000}} = 0.6 \times 10^{-12} NF$$

Proceeding as above the relation between gain and noise factor for a 2000 mc channel bandwidth is:

$$G = \frac{200}{1 - 0.6 \times 10^{-2} NF} \qquad (2)$$

This relation is tabulated in Table 5-6.

5. Recommended TWT Development Program

The TWT section of RCA at Harrison thinks it is practical to develop production designs for from five to seven rugged, reliable wideband TWT's employing periodic magnetic focusing that cover the spectrum from 700 to 12,000 megacycles. Such a program need not develop basically new ideas to be successful. The development problems are within the range of RCA experience and involve only time and manpower for their solution. While a TWT development program should include work on the electrostatic tube, the goal should revolve essentially about the magnetic type to ensure success.

The relative advantage of a ferret receiver based on these improved TWT's and one based on the conventional scanning superheterodyne has not yet been resolved. Assuming, for discussion, that this question has been decided in favor of the TWT, the problem areas are as follows:

a. Ruggedization. A structure for supporting the tube elements, the magnetic structure and the tube itself must be devised that is capable of withstanding the shock and vibration to be expected during the interval between launch and entry into orbit. An adequate shock and vibration testing program must be developed for this program.

b. Design of the Helix Assembly. Problems arise in connection with matching the coupling into and out of the helix over a broad band. Consideration must be given to frequencies well outside the passband. For example, it is not impossible for a broadbanded S-band tube to oscillate at L band.

In addition the match into the attenuator and the reproducibility of the attenuator require careful attention.

c. Periodic Magnetic Structure. This area is concerned with the tolerances, and the support of the permanent magnets and magnetic materials. The higher the flux density that can be attained, the less critical are some of the tube tolerances and the more flexible is the design.

d. Electrostatic Focusing. Problems arise chiefly in the shaping and the tolerance of the cathode magnet's field particularly in the transition region between the magnetic and the electrostatic focusing areas. Tolerances and support of all elements peculiar to the electrostatic tube are to be examined.

This development program will involve approximately 50 man years of engineering effort spread over 4 or 5 years. With this and the performance to be expected from improved TWT's in mind, there should be a basis for comparing the relative merit of the two forms of the ferret receiver.

E. VIDEO RECORDING

The magnetic recording equipment being proposed for storing the reconnaissance data in the vehicle until it can be transmitted to the communication station is one of the more complex components of the complete system. In considering ways to improve the reliability of video recording for satellite use, the problem has been subdivided into (1) tapes, (2) bearings, and (3) drives for the tape transport.

1. Tape Reliability

A polyethylene terephthalate plastic, Mylar, is used for the base material of the magnetic tpae. Compared with other plastic materials, Mylar has an exceedingly high tensile strength and is almost chemically inert. The chains of molecules are oriented so that the material will yield or stretch to a point, but beyond that point its strength will increase markedly. The tape is being operated far below the yield point so that stretch is not a problem in this application.

A relatively small loop of the tape, a variable speed drive, and a magnetic head has been set up to test the tape's qualities. After the equivalent of 10,000 hours of operation it showed only very slight signs of abrasive wear either from the sides of the reels or from the head itself. There is no evidence of wear caused by friction between adjacent windings of the tape. It is planned to use sapphire or diamond edge guides to keep the tape properly positioned.

The tape can operate in the temperature range of from -40° to $100^{\circ}C$. Temperature extremes do not alter the thickness or width characteristics of the tape sufficiently to cause concern in this application. Operation in a vacuum should have no ill effects on the physical characteristics of the tape, although operation <u>in vacuo</u> must be studied to make certain of this. If positioning the tape becomes a problem during the programming of the pickup and playback of the reconnaissance data, a special control track on the tape will be used for positioning the tape relative to desired information contained along its length.

At the present time tapes can be procured from the manufacturer in continuous 10,000-foot lengths. Arrangements can be made with the manufacturer to obtain 30,000-foot tapes, free of splices. Splice-free tapes will hold the loss of reconnaissance data to a minimum.

The pressure of the tape on the recording head was not measured, but is known to be extremely small. During recording and playback in a vacuum, the pressure of the tape on the head could be reduced because of the absence of air and gas molecules between them.

The coating used on the tape is an emulsion of gamma Fe_2O_3. These acicular particles are slightly less than one micron in length, and about 0.1 micron in diameter. During manufacture these particles are oriented by a magnetic field while the binder is in a plastic state. After 30,000 passes of the test tape (equivalent to approximately 8000 hours of actual operation) there was only slight evidence of noise in the recorded signal due to wear of the tape, and no evidence that loss of particles had degraded the quality of the signal. It is interesting to note that the magnetic tape would be required to record and playback a total of only 800 hours during a year's operation of the ARS vehicle on a 83° orbit.

The amount of wear between the tape and the head during operation in a vacuum at the rated speed is not known at present. As stated above it is thought that the necessary tension in a vacuum between the two for satisfactory operation will be low but this same lack of air and gas molecules will probably increase the friction between the two.

There do not seem to be any known poisons that affect the operation of the magnetic tape. The problem of physical embedding of particles (dust or metal) into the tape itself is one of the problems that will have to be resolved. The embedding of foreign particles will either displace the iron particles and produce a magnetic hole or it will keep the tape from coming into contact with the head.

The problem of "gunking", the accumulation of the binder on the recording head, is a severe one. As the binder builds up on the head it lifts the tape from the head and so degrades the quality of the signal. This problem varies with different tapes and its magnitude depends upon the physical characteristics of the binder used in manufacture. A temporary relief for this problem as concerned with the test loop has been effected by using a wiper near the head that is impregnated with a silicon oil. This tends to lubricate the tape and to remove the binder particles before they can collect on the head. This remedy cannot be used in a vacuum because the vapor pressure of the silicon oil is too great. This problem needs much more study and experimentation before a workable system with the desired reliability will be had. The best solution would be to find a binder that either would not come off the tape, or one that would not build up on the head.

Print-through, a form of crosstalk, is another problem with the magnetic tape in current use. Print-through occurs while the tape is wound on the reels. The magnitude of the effect is an inverse linear function of the thickness of the tape. This will be one of the limiting factors when attempting to use a thinner tape. The effect of print-through may be minimized by restricting the low frequencies on the tape. It is suspected that all forms of radiation will tend to make the problem worse. This problem should be studied to determine the magnitude of the print-through as a function of time in storage, and also to determine what effect if any particles of dust or metal would have on it.

Tape speeds of 100 and 400 inches per second are being considered. Both have their advantages, but the 100 inch per second speed offers the least problems. By using a system of frequency division a signal of 8-mc bandwidth can be recorded by breaking it down into four signals of 2 mc each. This can be done on one 0.5-inch 30,000-foot tape traveling at 400 inches/sec. The 8-mc signal may also be recorded at a 100 inch/sec tape speed by using frequency division and limiting the bandwidth of each channel to 220 kc. This requires 36 channels which can be had by recording nine channels on four 0.5-inch tapes, six channels on six 0.5 inch tapes, or by recording all 36 channels on one 2-to-3-inch tape.

The present plan is to mount several heads in a turret that can be rotated by signals from the ground; while one head is in operation the others could be cleaned. The present useful life of a head is approximately 1000 hours.

The random discharge of electrostatic charges developed by the tape can be a serious problem because of the resulting interference to associated electronic equipments. This problem has been successfully countered by employing grounded idlers which remove the charge before it can build to high potentials.

The possibility of employing magnetic tape that is coated on both sides is being explored. If this tape proves feasible it would result in an overall reduction of the size of the tape transport as well as the amount of tape needed.

2. Bearing Reliability

A major problem of running rotating machinery in a vacuum is that of lubrication. Lubricants that will function properly in ordinary applications are useless when employed in a vacuum because they boil off leaving the bearing dry. Several methods have been tried under Air Force contract number AF30(616)-2576 to remedy this situation. Morganite, a graphite compound, was used as a lubricant for a steel ball bearing assembly. The bearing was cleaned with carbon tetrachloride, rinsed with acetone and then packed with the graphite compound. The bearing showed less than 0.001-inch wear after 2000 hours of operation. When this bearing was tried in a vacuum it froze after a short running time. Another method used a low vapor pressure silicone oil to lubricate the steel bearings. The major difficulty was that the vapor pressure of the silicone oil was much too high for high vacuum operation. The other difficulty was that these oils tend to "creep", thus a bearing would become dry even if the oil did not boil away.

In the lubrication method that currently shows the most promise, the bearing is first thoroughly cleaned after which aluminum and then barium are vacuum deposited on the bearing. The bearing showed no apparent wear after 780 hours of operation in a vacuum of 45 microns, running at a speed of 3600 rpm, with a 6-pound radial load. This bearing is still under test. When barium was deposited directly on the steel ball bearing there was a severe problem of oxidation as soon as it came into contact with the atmosphere. The problem of oxidation does not seem of any consequence when the barium is plated over the aluminum.

Another approach to the problem of lubrication is to replace the steel balls with sapphire balls and run in the bearing dry. It is claimed that no lubricant is needed for this bearing material. An order for these balls has been placed with a French concern and experimental tests will be made as soon as they are obtained.

3. Drive Reliability

The feasibility study has indicated that it would be desirable to use a d-c motor as the prime mover. An electromagnetic clutch, the excitation of which is inversely proportional to the output speed, would couple the motor to the tape transport to obtain the constant speed drive required. It is planned to use reels that have a fairly large hub dimension so that the diameter differential between an empty and full reel due to tape pile-up will be as small as possible. A tape transport with a 20-inch diameter reel that is spoked like a bicycle wheel has been designed. With this transport only one inch of tape piles up for every 10,000 feet transported.

[redacted]

4. Rcommendations

a. Tapes. The reliability of the entire magnetic tape storage would be improved if the speed of the tape could be reduced. This would reduce the bearing problem, the length of tape necessary, the wear of the tape, and the size of almost every component of the system. Extensive efforts should continue on this problem. "Dusting", the loss of emulsion particles from the tape at the magnetic head is another serious problem. While these particles do not reduce tape life, their presence in a gravity-free environment could impede the operation of such equipment as bearings, relays, and optical equipment. This problem is much worse with new tapes; it reduces with the age of the tape. The RCA Laboratories are being supplied with a tape that has been processed to reduce this problem of dusting. Further examination is required to determine if dusting can be still further reduced by other means. If manufacturing techniques cannot be developed to reduce dusting to an acceptable minimum, then other measures will have to be employed. One possible approach would use a precipitator near the place that the dusting occurred to collect these particles before they could cause any harm.

Dirt or metal particles becoming embedded in the tape may become a very serious problem. These particles will scratch the head when passing over it; these scratches would in turn scratch the tape and reduce its useful life. The scratches on the head could become large enough to form slivers which would tear the tape and destroy the reconnaissance operation. The playback from the vehicle to the ground station can be monitored so that excessive noise can be detected. If noise does become excessive the defective head can be replaced by a clean one. While the reconnaissance data are being recorded no such monitoring can be accomplished.

[redacted]

Study and experimentation should be conducted to develop a method of keeping the tape clean. If it proves impractical to hermetically seal the entire tape transport, it might be advisable to brush the tape clean or to precipitate the particles immediately adjacent to those areas.

Tape tension must be maintained at a constant value to minimize the possibility of breaking the tape. Under the ARS feasibility contract, a system has been developed using servos that measure the tension of the tape and govern the speed of the winding and unwinding reels accordimgly. While this mechanism works very well, it introduces more rotating machinery and the attendant bearing problems. A mechanism now in the design stage promises the greatest reliability. It uses springs to maintain near constant tension on the tape as it winds or unwinds from the reels. The capstan then would be the only driven member. This will greatly reduce the chance of tape breakage, and will at the same time reduce the amount of electronic and rotating equipment in the vehicle.

The correct pressure of the tape on the recording head during operation in a vacuum can probably best be determined by experiment. This is also true for determining the friction between the tape and the head.

Gunking of the head can best be remedied while the tape is being manufactured. This problem could become much worse in vacuum operation because of the lack of water vapor. In this area experiment and tests in a vacuum will be of considerable value.

b. Bearings. The work that is being done on the vacuum evaporation of aluminum and barium on the steel ball bearings looks very promising, and further work along this line should be done. There are possibilities that other metals such as indium might do a better job. If indium could be used it would save the use of the aluminum and might result in a stronger bond to the steel. The bearings should be tested with the load they are expected to bear, at the rated velocity, and in the best vacuum obtainable. Work should continue with materials like sapphire to try to find others if sapphire balls do not prove to be satisfactory for the application.

c. Drive Mechanism. Instead of utilizing a d-c motor-magnetic clutch combination to obtain the constant speed drive for the tape transport, it might be desirable to use an all-electronic, frequency stabilized transistor converter to power a synchronous motor. The advantages are many. The transistor converter is efficient (approximately 80 percent) reliable, small in size, and contains no moving parts. The synchronous motor would circumvent the problem of brush wear that exists with the d-c motor. The transistor power supply synchronous motor combination could be packaged in the same space as the d-c motor-magnetic clutch combination.

The coupling between the prime mover and the tape transport may involve speed reduction or change of axis of rotation to conserve space. While belts might be used, serious problems may arise from the flexing of belts in a vacuum. It appears that a flat belt may be preferred to V-types. Chain drives are definitely not to be considered because of the problem of lubrication of the bearings in the chain.

Considerable study and testing must be done to determine the most suitable cooling arrangement for the bearings and the motor. The question of what type of insulation to be used in the motor will have a direct bearing on the type and amount of cooling employed. Insulations containing organic materials, generally, should not be used because of the problem of gassing and decomposition. The products of the decomposition and the gas itself may condense out on relay contacts and other critical parts causing faulty operation. Even spun glass insulation contains organic materials that would cause this difficulty. The silicones appear to lend themselves very well to high temperature, high vacuum work and should be investigated.

The size of the motor required for the drive of the tape transport is a function of the type of bearings used as well as the acceleration desired to obtain the required operating speed of the tape during the start of recording or playback.

F. CONTAINERS FOR PAYLOAD EQUIPMENT

1. Introduction

Packaging designs for the ARS equipment are influenced by the physical design of the vehicle, the environment of the vehicle, and the environment required for the equipment. These factors and their influence on the choice of a packaging design are discussed and then specific suggestions for a packaging design are given. These recommendations follow the physical design of the vehicle as specified by Bell Aircraft Corporation and the equipment requirements for an early test vehicle.

2. Environmental Factors

a. Acceleration in Ascent. It is understood that accelerations in excess of 10g at frequencies up to 1500 cycles are transmitted to equipment in ascent. These conditions therefore override the requirements for strength of materials in orbit.

b. The Temperatures in Ascent. The temperatures encountered in ascent are higher than those calculated to obtain at any point on the vehicle skin during orbiting. Moreover the skin temperature environmental to the payload volume with which this study is concerned is uniformally high during ascent but "spotty" and variable during orbiting.

However, the time of ascent is only 30 minutes, approximately, so that if a local element of payload is insulated from the vehicle during ascent and/or has sufficient heat capacity the temperature of this element will not rise intolerably during this time.

c. The Temperatures in Orbit. In orbit the temperature of the skin at the points of maximum variation range from about 385°F to -170°F. For reasons determined by vehicular stability it is desirable to place the payload containers in those volume regions which are subject to radiation and conduction from those adjacent skin areas of maximum temperature extremes.

However, the mean temperature in a particular location, the heat capacity of the particular chassis within a container, the operating temperature desired, and the heat generated within will determine whether insulation against heat conduction is desirable or not and what surface conditions must be provided for a given container housing a chassis.

3. Vehicle Structure

a. Mounting Facilities. In the design of the vehicular structure provision is made for annular frame braces of U-shaped cross-section spaced every 9 inches longitudinally along the skin of the payload volume of the vehicle. The flat face of the web of the U-channel just inside the skin provides a 2-inch radial surface which may be used for the support of payload containers. However, each ring consists of three equal ringed sections of 120° each to allow for transverse movement due to temperature changes. This arrangement prohibits the use of supports for the containers which might bridge the hinges unless flexibility in the new supports is also provided. Moreover supports from brace to brace must be provided with flexibility for longitudinal thermally-caused movement.

b. Vehicle-Borne Equipment. Below are tabulated data on the equipment anticipated for the early vehicle. Data are for each unit.

Designation of Equipment	Number of Units	Anticipated Operating Pressure	Approx. Dimensions (inches)	Internal Heat Dissipation when operating (watts)	Duty Cycle	Weight (lbs.)
Transponder	2	A+	5x5x13	40	1/10	20
Batteries	1	A	20x20x10	--	---	500
Clock and Order Storage	1	A	6x7x4	0.4	1	7
TV Camera	1	0	8x3x4	4	1/30	4
Telemetering	4	0	---	--	--	--
TV Communications	1	0	4x6x2	--	--	1 1/2

+A - Atmospheric

It will be noted that the largest container would be required for the batteries if these were all put into one container. However, in view of the large mass of the batteries, it would seem advisable to house them in four containers of approximately 1000 cubic inches each. This greatly reduces the bending moment on the supporting brackets and allows better weight distribution.

For those units for which atmospheric pressure operation is to be maintained a relief valve would be required. A suitable type having continuous settings from 0 to 20 psi - one among several makes available - is the Circle Seal Type P-249 valve particularly adaptable to use with thin materials since it is of the through type with backing nut. A 9/16 inch hole with a 0.56-inch I.D. by 0.75-inch O.D. washer is required. The operating temperature range is from -80 to 400°F with silicone "O" ring. The body material is aluminum.

Connecting plugs would be required for all units, of course, and hermetically sealed connectors for the pressurized units. Several manufacturers make these available.

c. Other Mechanical Considerations. Since allowance is made for thermally caused mechanical movement of the vehicle, both radially and longitudinally, similar allowance must be made for the containers attached and for chassis mounted within them.

Some of the chassis may require shock mounting; it should be determined that mechanical resonance does not build up to intolerable amplitudes.

Additionally the mass of the containers, chassis and mounting means should be a minimum consistent with mechanical strength.

To reduce bending moments on the supporting brackets attached to the frame brace, containers, particularly those housing heavy units, should be mounted close to the frame braces. However, they should not be allowed to touch the skin since conduction of heat to and from the skin, which experiences a large range of temperature variation, would then be encountered increasing the variation in the container. The presence of conduction might not be serious but would generally not be advantageous.

In addition the container supporting brackets should be poor conductors of heat, strong in relation to weight, of stiff material initially and tapered to take the cantilever thrust of ascent. It is believed that properly shaped beryllium brackets of no greater than 0.25-inch thickness would suffice for all projected mountings (see Figure 5-3).

In general a cylindrical configuration for a container is considered preferable to a spherical or rectangular one inasmuch as the vehicle is cylindrical and the frame braces are circular. A very-thin-walled cylinder, made thin to save weight, has great strength as a column particularly if it is reinforced with an internal framework to maintain rigidity. Since the internal framework can itself constitute a chassis without being made air tight, where the container itself must be finally air tight, it is in a convenient form for initial mounting of parts. Some form of final complete covering, preferably of polished aluminum or better is desirable in most cases to prevent direct radiation pickup. In addition, flange sealing is facilitated with a circular container.

However, for a chassis that does not have to be pressurized, the framework only with suitable end plates can serve as the container. Shock mounts may be directly attached to these end plates which in turn may be mounted to the frame braces as is the cylindrical container. A covering for the framework could be attached after the chassis was ready. In this case the framework could take the thrust or it could be made strong enough by the addition of the covering.

The use of shock mounts serves three purposes. In addition to providing shock mounting and suppressing high frequency vibration the mounts give heat conduction insulation to a chassis and constitute a thermal expansion joint. Without shock mounts a bellows type of cylindrical container could be used. However, for pressurized units restraining springs in tension appear necessary externally so that the force of the bellows as a piston would be restrained.

4. Suggested Container Arrangements

One arrangement believed feasible is shown in its several aspects in the drawing of Figure 5-3. Figure 5-3c is a cross-sectional drawing of a container mounted between braces. The view is that of Section A-A of Figure 5-3a which among other things depicts the design by the Bell Aircraft Corporation of the frame-brace hinging and its orientation relative to the plane of orbit. Figure 5-3b is a cutaway drawing showing an end view of the internal assembly. Figure 5-3d shows how the four battery containers are balanced with respect to the orbital plane. Figure 5-3e is drawn to make clear the proposed disposition of all units among the seven braces available. Some space between the two forward braces is required for the nose mechanism.

The drawings are not to scale since further research is necessary for exact choice of materials and configuration. Moreover only one sample box is shown although several sizes doubtless would be used when the character of each item of equipment is determined. Box size is flexible radially but not longitudinally except in steps determined by the distance between braces unless offset box mounting brackets are used.

In the scheme of Figure 5-3, an individual container has first an inner box fabricated of aluminum with "L" angles for the frame and an oversize circular end the outside edge of which serves as a flange. With or without sides and bottom, as required for the particular equipment to be mounted in it, this box is snugly fitted into a cylinder which has both ends flanged. The box flange and the cylinder flange at one end are then screwed to an outer plate. Shock mounts serve now to connect this plate with the brace mounting plate on one brace. The other end of the box is unattached but the flange on the same end of the cylinder is screwed to its end plate which in turn is supported by shock mounts to another brace spaced 9 or 18 inches longitudinally from the first depending on the length of the box. The cylinder constitutes the actual container. For those containers which are to be pressurized a ring seal between the box flange and the cylinder flange and a relief valve would be provided as indicated in Figure 5-3c. A connector would also be used in one end as shown. A hermetically sealed connector would be used for each pressurized unit.

The type of shock mount or vibration isolator illustrated in Figure 5-3 is that of the Barry Type 64-BA-40. Each is rated up to 40 pounds load and 15g shock. The temperature range of operation is indicated to be from about -240°K to 470°K (-35°C to 195°C or -35°F to 384°F). The effectiveness of this isolator in blocking high frequency disturbances in the range of 100 to 1500 cps would have to be particularly well investigated. For specific characteristics cooperation with manufacturers would be solicited and proof tests made on this as well as on all materials and assemblies.

A study of the mounting arrangement is that sketched in Figure 5-4. This arrangement might be used for a somewhat massive load or for one requiring support in the center of the vehicle. Inasmuch as the vehicular diameter is 62 inches and such supports could obstruct additional loading few could be conveniently used.

For this configuration the container assembly itself would be the same as for Figure 5-3c but each support plate would be rectangular and be attached to a set of trombone type cross members as shown in Figure 5-4. Each set of cross members would then be attached to frame braces spaced 9, 18 or 27 inches apart.

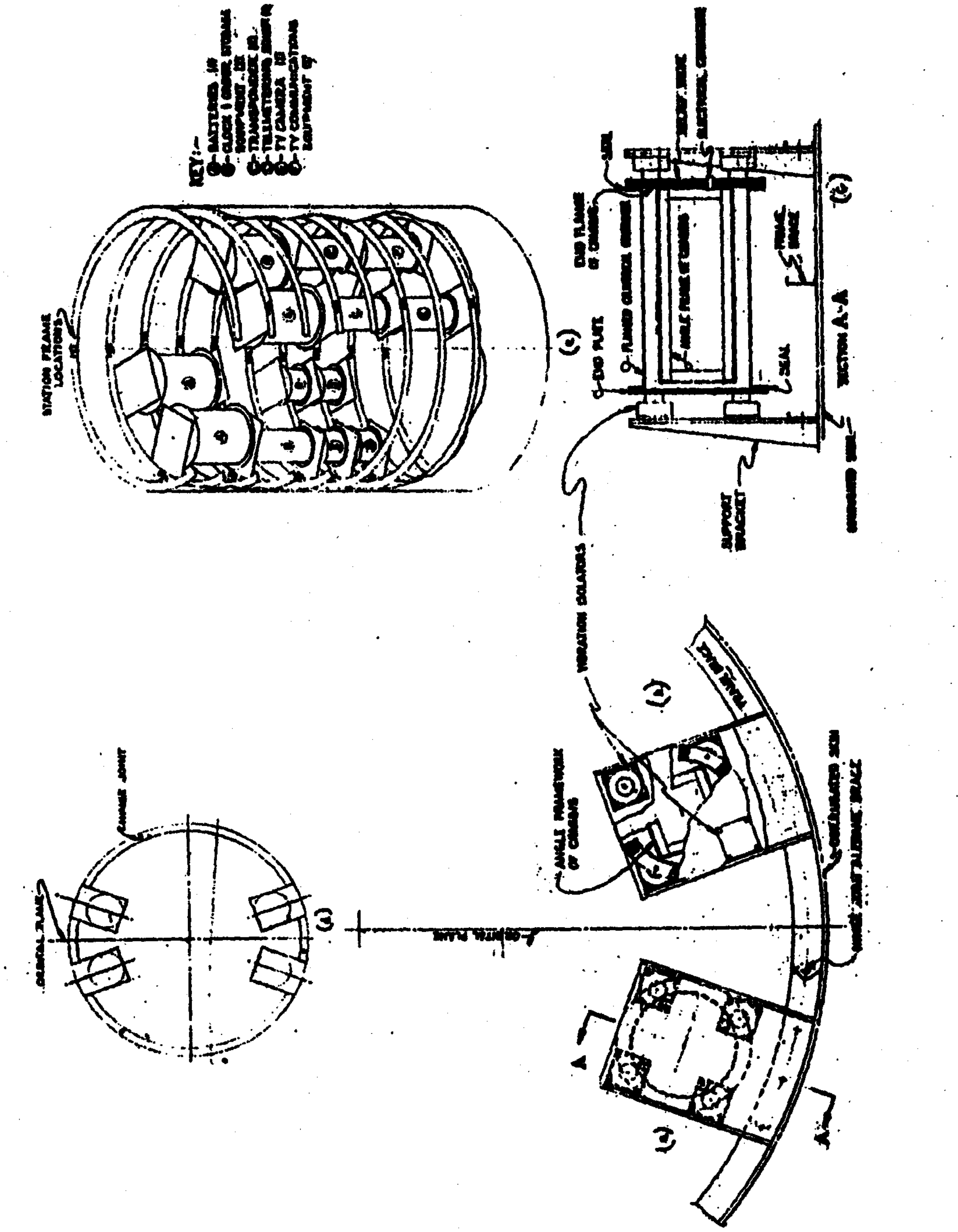

Figure 5-3. Suggested Container Arrangement

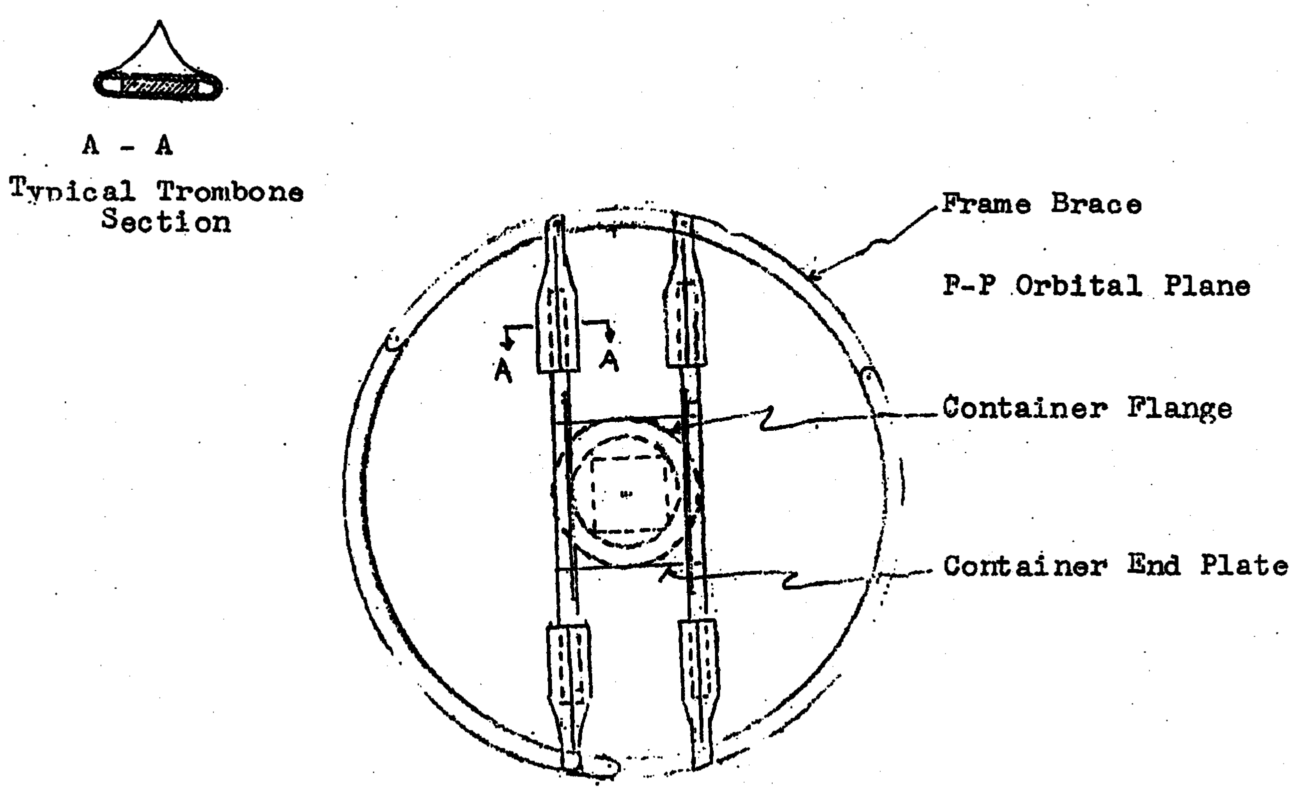

Figure 5-4. Container Support

CHAPTER VI

SPECIAL TEST EQUIPMENT

The ARS environment will be so unusual that much test equipment of a nature not usually found in electronics or aircraft laboratories, and much that represents a major item of expense will be required. Accordingly a brief study has been made of the required test equipment. Listed below are both major expensive items of test equipment and instruments not normally found in a well equipped electronics or aircraft laboratory. The majority of the test equipment described is for the purpose of environment simulation, but some items are for the testing of such special components as the radars and ferret.

It is naturally assumed that ordinary laboratory and factory test instrumentation will be available. By "ordinary" is meant such equipment as would normally be found in a concern specializing in the manufacture of electronic equipment. Such equipment would include AC and DC meters, oscilloscopes, tube testers, signal generators, optical benches, and shop facilities.

A. VIBRATION TEST EQUIPMENT

The vehicle and its components must successfully withstand the powerful vibrations generated by the ARS rocket motors. The rocket motors per se may be considered as sources of almost uniform accoustic noise. However, in a practical vehicle, resonances occur in the vehicle structure, the mounting brackets and the equipment structures so that the vibration applied to specific components is greatly accentuated in certain frequency intervals and attenuated in others. This makes it difficult to specify a vibration test that simulates realistically the conditions encountered in flight. However, performing the four tests described in the succeeding paragraphs will ensure a very high degree of reliability. The vibration tests must, of course, be followed by electrical tests to check for possible deterioration.

1. Component Tests

All components used should be tested at the level of vibration expected from the ICBM booster. A figure of 10g's has been given verbally for this booster, but it is not known whether this is the effective input or whether the effects of resonances have been included. Hence the exact specification of the test should be determined later. A preliminary estimate of a suitable test is as follows: Apply 20g of acceleration to the parts over the entire frequency range from 3 to 2000 cps. A suitable vibration exciter for this purpose might be the Model C10 produced by the M. B. Manufacturing Co. of New Haven, Connecticut or the equivalent. This equipment is capable of applying 1200 pounds of force to a load of over 50 pounds at 20g's, with automatic cycling of the applied frequency. The exciter and electronic power supply T51MC may be purchased for $15,305.

2. Subassembly Tests

Subassemblies, chassis and larger components should be tested on the same exciter. Because of mechanical resonances, these subassemblies should not be expected to withstand as great an acceleration as the components themselves. The exact specification should be determined later, but tentatively it might read as follows: Apply 10g's of acceleration to the subassemblies over the entire frequency range from 3 to 2000 cps.

3. Test of Overall Assembly

The entire vehicle (or at least the nose cone containing the complete payload) should be vibration tested as a unit. For this test perhaps 2 to 4g's (or more) should be applied to the assembly over the frequency range from 2 to 2000 cps. A suitable vibration exciter for this purpose might be the Model C100 manufactured by the M. B. Manufacturing Co. or the equivalent. This exciter with the P100 HA rotary power supply sells for $80,813. It can supply a vibratory force of 12,500 pounds. This amounts to 3.5g's on a 3500-pound vehicle. If more is desired, a Model C100 can be used at each end of the vehicle.

For this test, the vehicle should be suspended on cables so that the exciter does not carry the weight. The vibration is then applied to the end of the vehicle through a suitable connector.

4. Final Vibration Test

As a final test of vibration stability the complete booster and vehicle with payload should be mounted in a test stand and fired while held stationary. The payload should then be tested for deterioration.

5. Discussion of Vibration Testing

The tests described above should not be regarded as the basis for accepting or rejecting the equipment. It is believed rather that the tests should be a continuing aid to the development and design of reliable equipment. Many components and many structural arrangements will be tried and found unsatisfactory. A number of changes in components and changes in structure will be found necessary before satisfactory performance is obtained.

B. VACUUM CHAMBERS

Five vacuum chambers are suggested as environmental test equipment for the ARS vehicles: two high-vacuum ovens, of different sizes, a quick-pulldown chamber, an ultra-high vacuum chamber, and a low-vacuum oven.

1. High-Vacuum Ovens

Many components of the ARS payload, such as vacuum tubes, transistors, and batteries must be maintained in a specified temperature interval. Hence an important design factor is the transfer of heat from the walls of the vehicle to the payload. For design and test purposes, it would be desirable to simulate this heat transfer by means of some sort of oven.

Examples of the equipment which might be tested in this vacuum oven are the cameras and mirror wheel, the stable table, the tape recorder, the electronic gear, and the environmental instrumentation (such as geiger counters, microphones, resistance thermometers and ion gages). Another possible piece of equipment requiring testing is the electrostatic recording system, in which the cathode-ray gun would not be encased in a glass envelope. It would be of some interest to see whether stray gases, such as lubricant fumes, would have a deleterious effect on cathode emission.

Unfortunately, the implementation of the oven involves a basic difficulty: Because of the extremely low atmospheric pressures at satellite altitudes ($\sim 10^{-8}$ to 10^{-10} mm Hg), the air has practically no thermal conductivity so that the heat transfer from the walls to the payload takes place mainly by radiation. Simulating this environment on the ground requires a vacuum high enough to eliminate the effect of the atmosphere's thermal conductivity, a condition obtained at pressures below 10^{-4} mm Hg. Thus, properly evaluating the vehicle's temperatures requires a "vacuum oven" in which a source of heat is combined with an air pressure of 10^{-4} mm Hg or less.

Two types of vacuum ovens deserve consideration as test equipment. One is of medium dimensions for testing large components of the payload; the other is of large dimensions for heat testing the complete satellite or a large section of it.

The first type of vacuum oven is envisioned as a cylindrical chamber about 5 feet in diameter by 5 feet in length. It would contain a source of heat consisting perhaps of several electrical resistance coils which would surround the components to be tested. These coils could be heated to as high as perhaps 300°C. A rack would be provided for holding the tested components. If so desired sheets of aluminum or other metal could be placed between the heaters and the tested components in order to better simulate the hot walls of the vehicle.

Another useful provision would be individual temperature control of the heating coils. This would permit simulating the effect of a localized "hot spot" on a skin such as titanium that has low thermal conductivity. (Titanium has been seriously considered as a skin material because of its high strength-to-weight ratio.)

Two diffusion pumps with throat diameters of the order of 14 inches should be able to provide the oven with a vacuum of 10^{-5} mm Hg within perhaps an hour, assuming there is no large source of gas from the tested components. Even pressures as low as 10^{-6} mm Hg are attainable when special measures are taken, but such pressures are not likely to be required. To maintain the functional characteristics of any organic sealing materials (such as plastics or rubber) it will probably be necessary to cool the envelope of the chamber by hollow coils containing a liquid coolant.

Of course, provision for bringing electrical connections through the chamber walls would be necessary. In addition, glass windows for viewing the contents of the chamber would be convenient. These provisions are obtainable commercially.

In some cases it may be desirable to reduce one of the "heating" coils below ambient temperature; in that case one might use tubes containing a liquid for the purpose of both heating or refrigerating, whichever is desired. These tubes would replace the electrical heaters proposed above; the former would probably have the disadvantage of not being able to reach as high temperatures as the latter.

The price of a vacuum oven as described above would probably be in the range from $15,000 to $20,000, and it could be supplied by Consolidated Vacuum of Rochester, New York.

The second type of vacuum oven suggested is one large enough to contain either the entire satellite or a large section of it. It would be perhaps 8 feet in diameter and 30 feet long, and it would contain individually controlled heating coils and possibly refrigerating coils similar to those described for the smaller oven. Even in chambers of this size, vacuums of 10^{-5}mm Hg have been achieved when refrigerating baffles were used. However, because of absorbed and adsorbed gas and other sources of stray gas on the vehicle or in the chamber, a day or longer might be required to obtain that low a pressure.

The cost of such a test facility would be of the order of $100,000, and could probably be supplied by Consolidated Vacuum. This price would include the vacuum chamber, the diffusion and mechanical pumps, refrigeration baffles, and control equipment.

2. Quick-Pulldown Chamber

Some components, such as batteries, gyros, and gas bearings contain sealed-in gas, and are therefore subject to a mild shock from the rapid reduction in atmospheric pressure during launching. The pressure will drop to 1 percent of sea-level pressure within about 100 seconds and 0.1 percent within about 130 seconds. For test purposes, a vacuum chamber capable of producing such a rapid pressure reduction would be desirable. An appropriate size would probably be a 5 or 10-foot cube, or somewhere in between. Such chambers are commercially available; the prices are about $20,000 for a 5-foot cube and $100,000 for a 10-foot cube.

It has been noted that RCA has some vacuum chambers of the proper sizes at Camden, New Jersey, and that some time for their use could probably be allotted to ARS. However, these chambers produce a much slower pressure transient (1 percent of sea-level pressure in 10 minutes) than is expected in the tactical operation. Hence if these chambers are used the results would be only partially indicative of the tactical behavior of the tested components and more rigorous tests might still be necessary.

3. Ultra-High Vacuum Chamber

At satellite altitudes, the atmospheric pressure descends theoretically to somewhere in the range 10^{-8} to 10^{-10} mm Hg; these pressures can be achieved in the laboratory only by very special "ultra-high" vacuum techniques.

A small vacuum chamber (say 6 inches in diameter by 1 foot in length) providing such low pressures would make it possible to evaluate instrumentation such as ion gages or mass spectrometers that are sensitive to very small amounts of gas. Such instruments would be subject to [redacted] the vehicle, and it would be desirable to evaluate in the ultra-high vacuum chamber any measures taken to counteract the effect of the outgassing.

Unfortunately, this type of equipment has been built only in the laboratory[1], and is not at present commercially available.

4. Low-Vacuum Oven

Batteries for the vehicle will probably require a seal or a valve of some kind to prevent the electrolyte from boiling off in the low atmospheric pressures of the satellite. A preliminary test for the batteries could be provided by a chamber at a pressure of about 1 mm Hg, containing heaters for bringing the battery's temperature to its expected operating value. This chamber could be a cube with sides 3 to 5 feet long. Once the seals of the battery have proven effective, the battery could then be given further tests in the high-vacuum oven. The price of this low-vacuum oven would probably not exceed $2000.

C. THERMAL RADIATION TEST EQUIPMENT

Because of the lack of data on the absorptivity (α) and emissivity (ϵ) of the proposed vehicle skin materials, it will be necessary to design and construct an apparatus to measure the α's and ϵ's of the various materials of which the skin may be constructed. These tests will have to cover a wide range of frequencies, corresponding to radiation from expected vehicular temperatures, the temperature of the earth, and that of the sun. Radiation tests will have to be made also for complete

1. D. Alpert, "Experiments at Very Low Pressures", Science, vol. 122, no. 3173, pp. 729 - 733, Oct. 21, 1955.

approximately monochromatic light sources, such as sodium, mercury, and other arcs, or the output of a continuously variable monochrometer could be used. Measurement of the ratio of the intensity of the light reflected from a polished specimen of the material being tested to that direct from the source would give the reflectivity for light of that particular wavelength.

Because no commercial test instruments exist for the cavity emission measurements, a reliable cost figure cannot be given. If it is necessary to construct the complete concentric sphere system, the total cost might reach \$20,000, including vacuum equipment and measuring apparatus. If large existing vacuum-heat chambers could be employed, this figure might be halved. Probably the spectroscopic installation for obtaining α's as outlined above could be supplied for approximately \$10,000.

D. DUST ACCELERATORS

There is strong evidence that an ARS vehicle will be bombarded by meteoroids and dust particles in a wide range of masses (the great majority of particles having masses below 10^{-3} gm) flying at speeds on the order of 20 miles per second. The resulting erosion of such areas as the vehicle skin, the solar battery windows, and the television camera window may be a serious problem. On vehicles operating for several months, meteroid penetrations are expected to be of consequence, too. (See Final Report, ARS Research and Design Study, RCA). It therefore would be interesting and perhaps important to determine the effect of meteoroid and dust bombardment by means of some ground test equipment. Two techniques for obtaining the required particle velocities have come to our attention: explosive and electrostatic acceleration. The former technique has already been implemented, while the latter is at present only embryonic.

In constructing such a test facility, there are several principal requirements that must be met:

1) The particles must be accelerated fairly uniformly to a velocity on the order of 20 miles per second. This velocity, of course, must be ascertainable.
2) The particles must be of fairly uniform size, and the stream of particles optimally would be of uniform density, so that one could determine the effect of size on erosion.
3) The atmosphere through which the particles fly before impact must be controllable: pressures of 10^{-5}mm Hg should be obtainable. In addition, control of composition to take account of diffusive dissociation, molecular dissociation, and ionization of the atmosphere might be desirable. A high vacuum is especially important in order to avoid the frictional heating and conductive cooling encountered at pressures above 10^{-4}mm Hg. The vacuum equipment and other control apparatus must, of course, have protection from the explosions. This could be provided by thick steel plates or by concrete.
4) If explosive equipment is used, care must be taken to prevent the noise from disturbing neighboring communities.

1. Explosive Acceleration

The requirements outlined above apparently have been met to some extent by the equipment designed and operated under the direction of Dr. Thomas C. Poulter, at the Poulter Laboratories, Stanford Research Institute, Menlo Park, California. Presumably the basic technique of producing the required dust stream is by a hollow metallic cone embedded in TNT, as indicated in Figure 6-1. Under Poulter, several experiments on the effect of particles having a variety of sizes and velocities have been performed. Typically, the size of an enclosure for protecting the vacuum equipment and other control and measuring apparatus is about a cubic meter. The explosion usually takes place outside the enclosure.

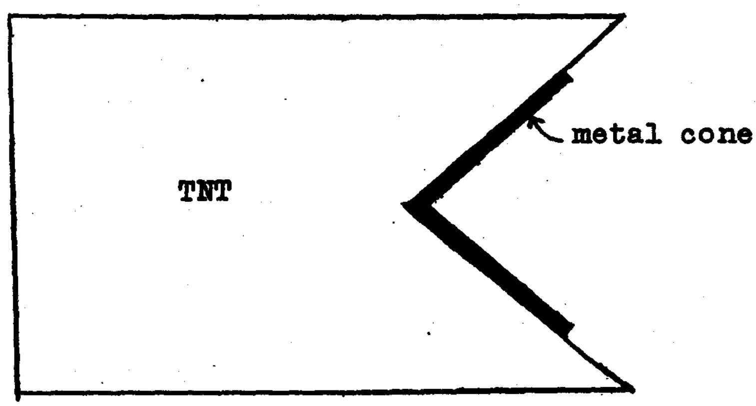

Figure 6-1. Cone Charge Arrangement.

The production of the required vacuum may not be much of a problem. A vacuum of 10^{-5}mm Hg is easily obtained in the present state of the art so long as the requirements on the cleanliness of the vacuum and on the rate of gas removal are not too stringent.

Although Poulter has done some work on the evaluation of meteoroid and dust bombardment, much more needs to be done. Army Ordnance contracts for further work related to Poulter's experiments have been awarded to Ramo Wooldridge, General Electric, and possibly AVCO.

Several reports on Poulter's work have been issued. However, these reports are classified, and for this reason could not be obtained in time for the present investigation.

2. Electrostatic Acceleration

Electrostatic acceleration of dust particles, recently proposed by S. F. Singer[1], is an interesting alternative to the explosion technique. It would have the advantage of requiring no protection from explosive shocks, and of providing convenient control of particle masses and velocities.

E. SOLAR BATTERY TEST EQUIPMENT

Special test equipment for solar batteries will consist of laboratory apparatus for use with individual cells and assemblies of a small number of cells, and outdoor test stands for large area assemblies. The laboratory equipment will include, in addition to ordinary laboratory apparatus, artificial sun sources and spectrographs; the outdoor test stand will have to be able to mount large sheets of cells, probably of 30 square feet in area.

1. Artificial Light Sources

The artificial sources of light could consist of two types: a xenon arc or a set of incandescent lights with special filters to reduce the infrared content. A xenon arc source may be purchased for approximately $500, but its life is short (on the order of 100 hours) and the source is a concentrated one. It does give a spectral distribution in the visible and shorter wavelengths that approximates that of the sun. The area covered by several silicon cells can be more easily illuminated by several incandescent floodlights, the light from which is filtered through a liquid in order to reduce the longer wavelength components. The absolute intensity of such a source is below that of sunlight, but it can be calibrated and used as a known testing source of light thereafter. The cost of such an installation would be very small, less than $100.

1. S. F. Singer, "The Effect of Meteoric Particles on a Satellite," Paper No. 307-56, American Rocket Society, 500 Fifth Ave., New York 36, N.Y. (Presented at the Semi-Annual Meeting of the American Rocket Society, June 18-20, 1956)

Standard ultraviolet arc light sources should also be available for testing the discoloration or crazing of plastic materials under long exposure. The price of these should be below $1000.

The temperatures reached by solar batteries operating in a vacuum will depend on their absorptivity and emissivity. Large scale vacuum heating tests are difficult to perform at ground level because of the "greenhouse" effects that arise from the transparent windows necessary to retain the vacuum while passing light to the cells. A more practical approach appears to lie in the use of spectroscopy to determine the transmission and reflection of the silicon cells (and also of mounting materials) from the visible to the far infrared wavelength regions. A possible source of nearly monochromatic light for these tests could be a Perkin-Elmer No. 83 Monochrometer. A glass prism will operate in this in the visible range, but to cover the range to 30 microns wavelength will require prisms made of such materials as quartz, CaFl, NaCl, and KBr. Various thermistors and vacuum thermocouples will be necessary as detectors; a tungsten lamp and a Nernst glower could function as sources. Estimated cost of the entire spectrographic equipment is $10,000.

2. Outdoor Mounting Stand

Overall tests should be made of the large areas of cells mounted and wired in the same plastic configuration as will be used in actual ARS vehicles, and connected to actual battery charging and voltage regulation and distribution circuits. Some tests can be made indoors with a battery of filtered lamp sources as described above, but tests with actual solar radiation should be made over an extended period. For this purpose an outdoor mounting stand capable of holding the solar panels at various orientations with respect to the sun should be constructed. This should be a relatively simple device, costing probably less than $1000. Provision should of course be made for leads from the test stand to the current handling and measuring circuits.

F. NUCLEAR RADIATION TEST EQUIPMENT

The effects of radiation from the nuclear auxiliary power supply on the remaining payload equipment must be determined. To obtain realistic reliability information it will be necessary to perform tests on a complete mockup of the missile structure with payload components operating in place. The exact nature of the tests can only be decided after the type of nuclear supply is determined.

The entire tests will have to be performed in an installation equipped to handle radioactively "hot" materials, and equipped for disposing of any materials made artificially radioactive during the tests. Thus if a nuclear reactor is started during the test, it is quite likely that various mounting and shielding materials can no longer be handled with safety.

Initial tests should have been made early by the reactor developer to forecast expected radiation levels at the payload locations. Then in a provisional mockup of the vehicle structure tests should be made of the measured radiation at the payload locations when the power supply is in operation. Measurements should be made with various types of counters and dosimeters to determine the strength of beta, gamma, and neutron fluxes. Final tests should be performed with equipment running and metered for an extended period.

G. FERRET TEST EQUIPMENT

To test the ferret equipment a complete set of microwave signal generators will be required for frequencies from 10 mc to 40 Kmc. The following is a list of suitable equipment. Equivalent equipment of other makes exists for some ranges and not for others.

Signal Generators

Model	Mfgr.	Frequency Range	Price
HP608C	H.P.	10 - 480 mc	$ 950.00
HP612A	H.P.	450 - 1,200 mc	$1200.00
HP614A	H.P.	800 - 2,100 mc	$1950.00
HP616A	H.P.	1,800 - 4,000 mc	$1950.00
HP618B	H.P.	3,800 - 7,600 mc	$2250.00
HP620A	H.P.	7,000 -11,000 mc	$2250.00
		Total	$10,550.00

(H.P. = Hewlett-Packard)

These signal generators are adequate for the type I ferret covering 700 to 11,000 mc. When later models are designed to go to 40,000 mc the following generators will also be needed.

EHF Signal Generators

Model	Mfgr.	Frequency Range	Price
HP626A	H.P.	10.0 - 15.5 Kmc	$3250.00
HP628A	H.P.	15.0 - 21.0 Kmc	$3000.00
SG2225	Polarad	22.0 - 25.0 Kmc	$4935.00
SG2427	Polarad	24.7 - 27.5 Kmc	$4935.00
SG2730	Polarad	27.27 - 30.0 Kmc	$4935.00
SG3033	Polarad	29.7 - 33.52 Kmc	$4935.00
SG3336	Polarad	33.52 - 36.25 Kmc	$4935.00
SG3540	Polarad	35.1 - 39.7 Kmc	$4935.00
		Total	$35,860.00

The latter part of the list seems high and the ranges short. The price may come down by the time they are needed. At the present time, no other equivalent generators are available, to our knowledge, above 20 Kmc.

At least three complete sets of signal generators will be needed, one for development, one for production, and one for field tests. The field test equipment should be mounted in one or more trailers. The cost of the three sets of signal generators is $139,230.00.

H. BORESIGHT TOWER FACILITY

A boresight tower facility will be required at each tracking and communication station to align and test the station's acquisition and tracking radars. This facility will be located approximately 1500 feet from the radars and will comprise:

1) A -150 foot foresight tower bearing
2) Optical and radar "bullseyes" or targets to facilitate radar and telescopic observations at the radar sites.
3) Connecting waveguide between the radar "bullseyes" and test equipment located at the base of the tower.
4) Cables linking the facility to the tracking radar.
5) A transponding signal generator of about 10 watts capacity with microwave attenuator. If there is more than one radar "bullseye" a microwave switch will be included.
6) Communication and power line terminal equipment
7) A shelter at the tower's base to house some of the above items.

This facility will cost about $29,000. Its functions include:

1) Aligning the tracking radar's tracking and telescopic axes.
2) Calibrating the tracking radar's data takeoff in terms of local grid coordinates.

3) Checking the alignment between the tracking radar's tracking and difference pattern axes.
4) Checking for the presence of troublesome ground reflections which tend to degrade tracking accuracy.
5) Checking the tracking radar's dynamic range.
6) Adjusting the acquisition radar's data takeoff to ensure accurate designation to the tracking radar.
7) Roughly checking the working condition of both radars.

CHAPTER VII

RELIABILITY MODELS

A. INTRODUCTION

The study of the reliability of complex mechanism utilizes to a considerable extent probabilistic models and techniques that have been developed for use in the study of waiting lines, brownian motion, genetics, epidemics, nuclear reactions, and anthropology. Various of the techniques for analyzing these models either analytically or by sampling methods have application to reliability studies.

It would be impossible in this report to give an adequate treatment of these topics but it is useful to consider some of the ideas involved and their specific application to reliability analysis.

B. TYPES OF FAILURE

It is customary to consider that failures can be classified as catastrophic failures or as deterioration failures. Catastrophic failure is thought of as happening suddenly and being completely disabling to the apparatus. Deterioration failure on the other hand implies gradually less satisfying operation of the apparatus until it is judged to no longer be operating in a useful fashion. The opening of a resistor would be a catastrophic failure whereas a gradual drift in resistivity would lead to a deterioration failure.

Catastrophic failure is often split into the categories of "random failure" and "wearout failure". The names are so suggestive as to need little amplification; however, the distinction is extremely fuzzy and an example of the extreme conditions is helpful. A fixed amount of time to failure is often thought of as a wearout failure; a fixed probability of failure during any operating time interval of fixed length t, regardless of the past history of the system, is considered a random failure. In most practical cases of interest the completely determined time to failure seldom occurs. Whether a failure is classified as random or wearout depends to a large extent on the spread of the failures in time and the knowledge about the underlying mechanism of failure.

It should be noted that it is extremely common for two different failure mechanisms to be present in the same piece of equipment. Many electron tubes are subject to both random and wearout failure.

C. CATASTROPHIC FAILURE MODELS

The simplest example of a catastrophic failure model is the simple coin tossing game described in every text on probability. It is useful here since it exemplifies in a very simple form many of the ideas underlying some of the catastrophic failure models in general use. Consider, for example, a relay which is supposed to operate once every second. Suppose, further, that the probability of its operating at any given time it is supposed to operate is $\underline{p}$ and this probability is fixed for all time periods. From the point of view of reliability a sensible question to ask is what is the probability that the relay will operate exactly $\underline{k}$ (K = 0, 1, 2, ...) times prior to its first failure. The answer is obviously

$$(1) \qquad p^k(1 - p); \; k = 0, 1, 2, \ldots$$

which is the formula for the geometric distribution. From this it is then easy to answer another question of some interest, namely "mean number" of operations prior to first failure. This is given by

$$(2) \qquad \sum_{k=0}^{\infty} kp^k (1 - p) = p/(1 - p)$$

and the variance of the distribution is given by

$$(3) \qquad \sum_{k=0}^{\infty} \left(k - p/(1 - p)\right) = p/(1 - p)^2.$$

It is interesting to note that knowing this result it is very easy to answer some seemingly more difficult questions immediately. Suppose n relays are all independently operated and each relay acts in the same manner as the one described above. A sensible question to ask is what is the probability that all the relays fail simultaneously for the first time, on the k + 1 st operation. This is of course given by

$$(4) \qquad \left(1 - (1 - p)^n\right)^k \; (1 - p)^n \quad ; \quad k \; 6$$

where $1 - (1 - p)^n$ replaces p in (1). Similarly the mean number of operations to first failure is given by

$$(5) \qquad (1 - (1 - p)^n / (1 - p)^n = p \sum_{i=1}^{n} 1/(1 - p)^i.$$

Similarly the variance is

$$(6) \qquad (1 - (1 - p)^n / (1 - p)^{2n}.$$

Utilizing the formulas (4), (5) and (6), properly, indicates the advantages of redundancy.

The Geometric distribution has the following very interesting property; if the relay has not failed prior to the n th trail the probability that it will last k more trials is independent of n and is exactly the initial probability that it would last k trials before failing. This can be noted formally by writing the conditional probability, $P\ (n + k \mid n)$,

$$(7) \quad P(n + k \mid n) = p^{n+k}(1 - p) \,/\, p^{n} = p^{k}\,(1 - p)$$

The analogous distribution in continuous time is the "Negative Exponential Distribution" which can be defined by the equation

$$(8) \quad P(x > t) = \int_{t}^{\infty} \lambda e^{-\lambda s}\, ds \quad ; \ t \geq 0$$
$$= e^{-\lambda \tau}$$

where $P(x > t)$ is the probability that the first failure occurs after the time t. As with the geometric distribution it is easy to see formally that history has no effect on this failure process. Suppose that it is desired to find the conditional probability, $P(x > t + t_o \mid t_o)$, that the first failure occurs after time $t + t_o$ given that it has not occurred before time t_o. As in equation (7) this can be written

$$(9) \quad P(x > t + t_o \mid t_o) = \frac{P\ (x > t + t_o)}{P\ (x > t_o)} = \frac{e^{-\lambda\ (t + t_o)}}{e^{-\lambda t_o}}$$
$$= e^{-\lambda \tau}$$

which is independent of t_o.

The negative exponential failure law is one which appears to apply to a large family of items such as electron tubes, resistors, and capacitors. It also has important applications as the "Limit Law" for failure of complicated systems under steady state conditions.[1] The negative exponential law depends on a single

1. Drenick, R. F. "A Statistical Reliability Theory" RCA EM-4221, April 5, 1956

parameter λ which in reliability nomenclature turns out to be the failure rate or hazard[1] (in statistical literature this parameter is referred to as the scale factor.) The mean of this distribution turns out to be . Another useful feature of this distribution is the addition of failure rates, that is to say if there are n independent items each failing with failure rate λ_i ($i = 1, 2, \ldots, n$) then the failure rate of the entire apparatus is

$$\sum_{i=1}^{h} \lambda_i .$$

A simple wearout model which is not completely deterministic might arise in the following manner. An apparatus lasts a length of time directly proportional to the number of relays closing in a single operation. The probability that exactly k of the n relays will close is

$$(10) \quad \frac{n!}{(n-k)!\, k!} \; p^k \, (1 - p)^{n-k}$$

This is recognizable as the Binomial distribution with probability p and number of trials n. The expected value of this distribution is np and the variance is np(1-p). This is a simple example of a chance wearout procedure.

In many problems a continuous analogue of this distribution arises. In the context of reliability this analogue is in the form of a "Truncated Normal" distribution truncated at zero. The probability P(x t) is given by

$$(11) \quad P(x>t) = \frac{1}{1 - \Phi\left(-\frac{\mu}{\sigma}\right)} \; \frac{1}{\sqrt{2\pi}\,\sigma} \int_t^{\infty} e^{-\frac{1}{2}\left(\frac{s-\mu}{\sigma}\right)^2} ds$$

1. The failure rate is defined as $-d\left(\ln P(x>t)\right)/dt$

where

$$(12) \quad \Phi\left(-\frac{\mu}{\sigma}\right) = \int_{-\infty}^{-\frac{\mu}{\sigma}} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}s^2} ds$$

which is extensively tabulated. It should be noted that for finite standard deviation, $\sigma < \infty$, and for the mean very much greater than the standard deviation, $\mu >> \sigma$, that $\Phi(-\frac{\mu}{\sigma})$ tends to zero and the probabilities in (11) approach very closely those of the Normal Distribution. The truncated normal distribution has a background of use in biological reliability applications.[1]

Another distribution which has a background of use in biological applications is the "Log Normal Distribution". This distribution is characterized by the distribution function

$$(13) \quad P(x > t) = \frac{1}{\sqrt{2\pi}\,\sigma} \int_{t}^{\infty} \frac{1}{s} e^{-\frac{1}{2}\left(\frac{\ln s-\mu}{\sigma}\right)^2} ds; \quad 0 \leq t < \infty$$

$$= \frac{1}{\sqrt{2\pi}\,\sigma} \int_{\ln t}^{\infty} e^{-\frac{1}{2}\left(\frac{s-\mu}{\sigma}\right)^2} ds$$

The distribution has mean $M(x)$ given by

$$(14) \quad M(x) = e^{\mu + \frac{1}{2}\sigma^2}$$

and variance $V(x)$ given by

$$(15) \quad V(x) = e^{2(\mu + \sigma^2)}\left(1 - e^{-\sigma^2}\right)$$

1. Bliss, C. I., "The Calculation of the Time Mortality Curve" Appendix by W. L. Stevens "The Truncated Normal Distribution" Annals of Applied Biology 24, 1937, 815-832.

Another quantity of interest in this distribution is the median $M_d(x)$ which is given by

(16) $M_d(x) = e^{\mu}$

This distribution has been widely used in bioassay in the analysis of "Quantal Response".[1]

Other distributions that have been considered as failure laws are:

1) The Gamma Distribution with distribution function

(17) $$P(x>t) = \frac{\alpha^{\beta}}{\Gamma(\beta)} \int_{t}^{\infty} s^{\beta-1} e^{\alpha s} \, ds \quad ; \quad t>0$$

which reduces to the exponential distribution in case $\alpha = 1$. The mean of this distribution is $\frac{\beta}{\alpha}$ and the variance $\frac{\beta}{\alpha^2}$.

2) The Weibull distribution with distribution function

(18) $$P(x>t) = \alpha\beta \int_{t}^{\infty} s^{\beta-1} e^{-\alpha s^{\beta}} \, ds \quad ; \quad t>0$$

which has arisen in connection with problems of metal fatigue. The mean $M(x)$ of this distribution is

(19) $$M(x) = \frac{\frac{1}{\beta}\Gamma\left(\frac{1}{\beta}\right)}{\alpha^{1/\beta}}$$

The variance $V(x)$ is

(20) $$V(x) = \frac{\frac{2}{\beta}\Gamma\left(\frac{2}{\beta}\right) - \frac{1}{\beta^2}\left[\Gamma\left(\frac{1}{\beta}\right)\right]^2}{\alpha^{2/\beta}}$$

It should be noted that if $\beta = 1$ this is the negative exponential distribution.

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1. Finney, O. J., "Probit Analysis" Cambridge 1952

Commonly items may be subject to failures in more than one way. For example the item may fail in a purely random fashion up to some time $\underline{t_o}$ and at time $\underline{t}$ completely disintegrate. If the random failure is exponential, the distribution function would be described by

$$(21)\quad P(x>t) = \frac{e^{-\lambda t} - e^{-\lambda t_o}}{1 - e^{-\lambda t_o}} \quad ; \quad t \leq t_o$$

$$= 0 \quad ; \quad t > t_o$$

This distribution is known as the truncated exponential with point truncation t_o and has mean $M(x)$ given by

$$(22)\quad M(x) = \frac{1}{\lambda} - e^{-\lambda t_o} \left(\frac{1}{\lambda} - t_o\right)$$

The more common case is for the random failure and wearout failure to both be specified by probability distributions. The necessary probabilities can be obtained by noticing that if the probabilities of lasting a time $\underline{t}$ are $P_1(x>t)$ and $P_2(x>t)$ for the two distributions then, if the two distributions are independent, the probability of the item lasting longer than time $\underline{t}$, $P(x>t)$, is given by

$$(23)\quad P(x>t) = P_1(x>t)\ P_2(x>t).$$

Before treating another topic it is useful to consider somewhat how this type of failure is related to what might be called a process. In most of the catastrophic failure problems the idea has been to code the output of the equipment as a function of time either 0 or 1 for operation or failure respectively and in the case considered here there is no return from failure. The process then consists of going along with output zero until there is a sudden jump to one and then continues indefinitely with value one. Each of these infinitely many step function graphs is a conceptual graph of the process. The probability $P(x > t)$ is the measure of, loosely speaking, the fraction of graphs where the jump does not occur until after the time t.

In the process where there were n relays the output was coded in such a manner that only if all n of the relays failed would there be failure. One could consider this as a system having a number of states which could be labeled S_o, S_1, S_n, where the state S_i occurs if i relays fail to operate. If this were graphed with $S_i = i$ the output would be represented by a graph having n levels. In the case considered here when the graph arrived at the n^{th} level it never returned to any lower level. The state S_n would be called an "absorbing state" or n would be called an "absorbing barrier". The function never goes below zero but if it arrives at zero it may return to any level. The state S_o is then called a "reflecting state" and the level zero is called a "reflecting barrier". The process defined by the relays, if S_n is made a reflecting state, has the property that the probability distribution of the S_i is the same at all time intervals. This property is called "stationarity" and the process is a "stationary process". The process defined by the relays, if S_n is an absorbing state, has the property that the value of S_i at any time point never depends on the value of S_i at more than the preceding time point. (In this somewhat degenerate case it is totally independent of the preceding time point if the state at that time is different than S_n.) This is the "Markov" property and the process is a "Markovian" process.[1]

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1. A detailed but elementary discussion of Stochastic processes is contained in Feller, W. "An Introduction to Probability Theory and Its Applications" Vol. 1 New York 1950 and Bartlett, M.S., "An Introduction to Stochastic Processes with Special References to Method and Applications" Cambridge 1955

These properties are of some more importance in the next section on deterioration models.

D. DETERIORATION FAILURE MODEL

A simple way of looking at deterioration is to consider that the output of the apparatus has three possible states; S_o or a satisfactory state, S_1 or a tolerable state, and S_2 or an unsatisfactory state. Consider an output that stays in S_o for a while then changes to S_1 and finally goes to S_2. In deterioration models it is necessary to specify in detail what constitutes the state S_2.

Two simple examples of a deterioration procedure may help clarify the situation. Suppose the resistivity R of a resistor drifts in a linear fashion as a function of time and there is a value R_o which is critical , i.e., if $R > R_o$ then the resistor is considered inoperative. Here the state S_2 is categorized by $R > R_o$. Another example would be a resistor the value of whose resistivity is noisy and can only be specified in terms of a normal distribution with fixed mean μ_R and variance $\sigma_R(t)$. Suppose the critical thing was that there be a probability of .95 that $|R - \mu_R| < \epsilon$. Then the state S_2 would be defined by $1.96\sigma_R(t) > \epsilon$. In practice most deterioration is of a mixed nature. A symptom of wearout is often the increase in component "noisiness".

It is often desirable to attempt to compute the effects of component deterioration on system performance. This of course entails a mathematical formulation of the problem to express system performance as a function of component performance. It also means specification of component performance characteristics in terms of specified probability distributions. Last it involves specifying the failed state for both component and system. If the representation of the system is linear and the probability distributions involved are Gaussian then the system will have Gaussian fluctuations. If some other situation prevails such as non-linear representation or a different type of noise then the problem is much more difficult.

One method of approximation is to assume that all fluctuations are Gaussian and to use a linearized representation of the system. This technique has been exploited with some useful practical consequences.[1] More complicated approximations have been suggested but no extensive work has been carried out. The papers, by Meredith etal, contain an excellent description of the use of linearized Gaussian approximations.

A useful method in studying such stochastic problems is to see if "Steady State" or limiting processes are good as approximators. This has been used in telephone switching reliability problems but only in the most rudimentary fashion to other reliability processes.

The last technique depends on simulating the mechanism by using a computer and sampling with noise inserted in the circuit.[2] This type of work has been done extensively in simulation of military electronic systems but seldom on study of components. Suggestions for such study will be contained in the next section on Monte Carlo Techniques.

E. MONTE CARLO TECHNIQUES

"Monte Carlo Methods" may be described as devices for studying an artificial model of a mathematical or physical

1. Benner, A. H. and Meredith, B. "Designing Reliability Into Electronic Circuits" EM-4208 RCA 1954. Meredith, B and Portras, D. J. "Reliability of a TV Camera Chain" TR-1095 RCA 1956
2. Bennett, R.R. "Analogue Computing Applied to Noise Studies" Proceedings I.R.E. 41 1943

process. The technique is not new and was consciously used by gamblers for establishing pay offs in dice games. The first conscious modern use as a mathematical tool is probably due to "Student"[1], who used sampling to give some semblance of reasonableness to his conjectures concerning sampling distributions. The modern vogue stems from four sources:

1) Random walk models for study of nuclear processes.[2]
2) Noise studies in connection with electronic equipment.
3) Study of industrial and military operations.[3]
4) Mathematical use in solving systems of equations and integrating multiple integrals.[4]

The techniques most applicable to the study of reliability have their genesis in the first three sources. Procedures for improved sampling techniques often stem from use in mathematical problems but we shall not discuss such matters in this section.

The first place for applying a sampling technique arises in studying the operation of apparatus which is composed of n components each with failure distribution $P_i(t); (i = 1,,n)$. The technique is both simple and obvious. Pick an n-triple of numbers $(t_1, t_2,,,t_n)^{(\ell)}$ where $t_i (i = 1,,n)$ is picked at random

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1. Pen Name of William Gossett, a Brewmaster for Guinness.
2. "Monte Carlo Methods" National Bureau of Standards. Applied Math Series-12.
3. Lavin, M. M. and Schuller, D. H. "The Determination of Requirements for Warehouse Dock Facilities" Jour. Opns. Res. Soc. America 4 1956.
4. "Proceedings of Symposium on Monte Carlo Methods, Gainesville (1954)" (in process of publication)

from a population having distribution $P_1(t)$. Set

$$(24) \qquad t^{(\ell)} = \min_{\ell=1,,n} (t_1,,t_n)^{(\ell)} \quad ; \ell = 1,,N$$

Repeat the experiment N times; it is then possible to construct a histogram of survival times and to compute means variances and so forth of survival times.

A second interesting problem is one in which there are n parts which fail temporarily in time each according to the same distribution P_1 and are restored in time according to a distribution P_2. The problem is then to find the first time when all parts have simultaneously failed.[1] This can be recognized as a problem of waiting lines with n servers and the problem is that of finding the first time all the servers are busy or alternatively the length of period when no one is waiting. The procedure is again simple. For each component $C_i, (i = 1,,n)$, sample a sequence number pair $(t_1, t_2)_i^{\ell}$ with t_1 from a population with distribution P_1 and t_2 from a population with distribution P_2. List the down periods for each C_i. The k^{th} down period on the i^{th} component extends from

$$\sum_{\ell=1}^{k-1} (t_1 + t_2)_i^{(\ell)} + (t_1)_i^{(k)} \quad \text{to} \quad \sum_{\ell=1}^{k} (t_1 + t_2)_i^{(\ell)} .$$

Use the computer to check the smallest value of $\sum_{\ell=1}^{k-1} (t_1 + t_2)_i^{(\ell)} + (t_1)_i^{(k)}$, for which all components are down. Repeat the process to get histogram and moments.

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1. Harris, T. E. "A Model for Reliability of Complex Mechanisms" Rand RM-302, the RAND Corporation, Santa Monica, California.

A third possibility, based on computer simulation of noise in electronic equipment, can be performed as follows. Set up a system of equations relating system performance in time to component performance. For each component use a noise generator to simulate the components random values in time. Then run the computer recording the first time t, the output of the simulated system goes outside tolerable bounds. Repeat the process to get histograms, means, and variances of time to first failure.

The three suggestions above are examples of possible applications of "Monte Carlo Techniques" to reliability studies and are representative of the range of problems covered. These techniques are of course not substitutes for analytical methods but rather useful tools when analytical methods are unavailable for the problem in hand.

CHAPTER VIII

ENGINEERING APPLICATIONS OF RELIABILITY MODELS

A. EXPONENTIAL MODEL

1. Basis for Applicability

The "purest" definition of catastrophic failures would be restricted to those arising from an unforeseen defect in a basic material, viz. the chance defect in a crystaline structure or a rare delay in gas ionization. The discussion given here would broaden the scope of the term "catastrophic failure" to include those component part malfunctions beyond the control of all reliability engineering techniques. This interpretation is identical with that employed for the prediction of reliability in such advanced electronic systems as guided missiles and high-performance aircraft.

The study of electronic system reliability is essentially an Operations Research endeavor in its broad scope and vital concern with engineering details. Despite its complexities, however, it is possible to derive engineering constants and parameters suitable for predicting the reliability of electronic equipments and systems. For this purpose a "master plan" can be formulated as a guide for correlating past practices and results with the most probable future expectancies.

Figure 8-1 illustrates the fact that the position of the component becomes crucial at the time of its <u>selection</u> for circuit usage. Prior to this time much is invested in the "hereditary" characteristics of the parts. After this time many "environmental" aspects of the part usage enter into the reliability picture as <u>stress</u> factors. The general flow of engineering investment is a complex matter entailing simultaneously an accumulation of materials and processes and an accumulation of economic cost. The extent and impact of economic support of the ARS program will determine the degree of technological "break-through" possible in the area of component-part reliability. An example from recent engineering history, the development of the Bell Telephone transatlantic cable demonstrates the interrelationship between economic and technological factors in extending component reliability far beyond the initial state of the art. The great advances to be made <u>now</u> toward more reliable electronic systems must be made in the judicious exercise of the most promising component application techniques.

2. Underlying Concepts

a. Two Basic Experiments. Fundamentally there are two basic experiments which can be performed in deriving valid component failure-rate data. There is first the experiment of taking a group of similar component parts as a test sample, placing them in a compromise (standard) stress condition and observing the time and number of failures occurring. From this experiment certain statistical evidence can be derived.

The second basic experiment is the operation of a heterogeneous array of component parts within a typical electronic equipment of a given design. The uncertainties and circumstances of these two experiments are vastly different. However, by obtaining data from the first experiment and interpreting these data in terms of the second experiment, it is possible to derive valid component failure-rate information. Furthermore, there are other sources of pertinent engineering data. Two such sources are (1) the comprehensive literature on the properties and grading of basic engineering materials, and (2) the pertinent but somewhat fragmentary data reported from the field on component failure.

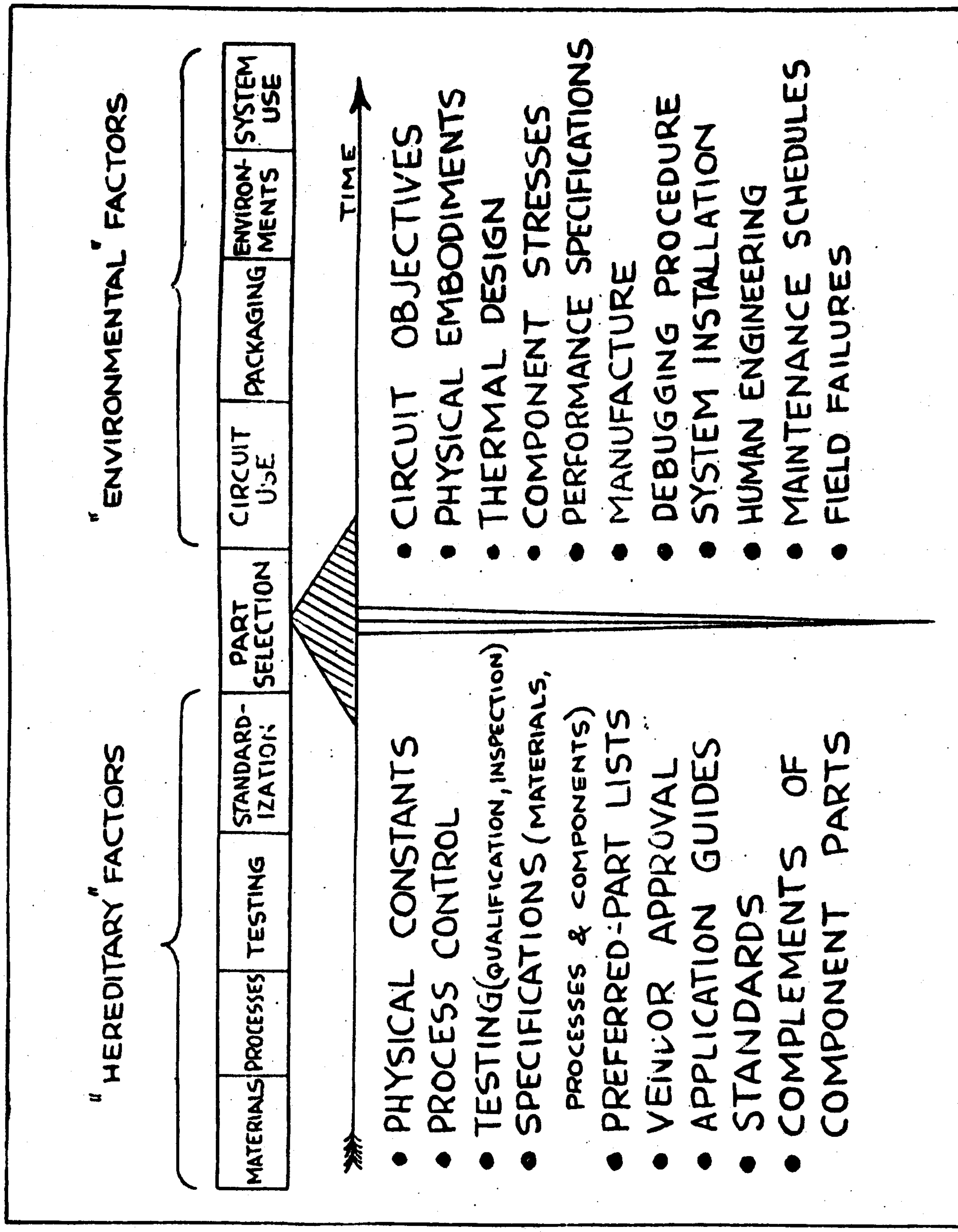

"HEREDITARY" FACTORS
"ENVIRONMENTAL" FACTORS
MATERIALS
PROCESSES
TESTING
STANDARDIZATION
PART SELECTION
CIRCUIT USE
PACKAGING
ENVIRONMENTS
SYSTEM USE
TIME
• PHYSICAL CONSTANTS
• PROCESS CONTROL
• TESTING (QUALIFICATION, INSPECTION)
• SPECIFICATIONS (MATERIALS, PROCESSES & COMPONENTS)
• PREFERRED-PART LISTS
• VENDOR APPROVAL
• APPLICATION GUIDES
• STANDARDS
• COMPLEMENTS OF COMPONENT PARTS
• CIRCUIT OBJECTIVES
• PHYSICAL EMBODIMENTS
• THERMAL DESIGN
• COMPONENT STRESSES
• PERFORMANCE SPECIFICATIONS
• MANUFACTURE
• DEBUGGING PROCEDURE
• SYSTEM INSTALLATION
• HUMAN ENGINEERING
• MAINTENANCE SCHEDULES
• FIELD FAILURES

Figure 8-1

Before going into any detailed discussion of how a specific class of component parts can be traced from its "test phase" to its "application phase", the characteristics of the two basic experiments must be described further. For this there is required a threefold consideration; a need to describe the phenomena most commonly observed; the establishment of a rudimentary (but adequate) mathematical model; and a first-order recognition of the physical uncertainties associated with the two fundamental experiments.

b. Phenomena Most Commonly Observed. Tests usually performed on component parts are seldom planned in a manner or obtained in numbers usually considered sufficient for statistical purposes. This is primarily a result of economic and time limitations. Yet even when life tests are conducted with numerous practical limitations, the results follow the characteristic shown in Figure 8-2A. While variations from this characteristic are commonly observed, they do not distort the basic trend since they are not extreme and apparently are as likely to occur in either direction from the norm. The gross engineering evidence is that the characteristic of Figure 8-2A is suitable for the consideration of most component parts by families (types) and for repeated application in complex electronic systems.

Both the early debugging period of a component test group and the wearout phenomenon of Figure 8-2A are characteristic of life testing. The most important fact to note here is that debugging and wearout phenomena are essentially random from the point of view of the individual part, but certainly they are of a different order or "randomness" than are the individual failures. For example, an individual vacuum tube is always in the process of depleting its cathode material reserve. There is no doubt that is will fail although the exact moment that failure will occur cannot be predicted. The time at which a group of vacuum tubes will pass its characteristic maximum failure rate, however, can be predicted from life testing. Figure 8-2B illustrates the way in which this group characteristic can be depicted.

Experience from component testing indicates that some failures that occur after the debugging period (in addition to the group wearout characteristics) have been accumulated over a long operating period in what may be designated as a "pure" random fashion. These failures represent a degree of randomness harder to cope with on an engineering plane. If they did not exist, it would only be necessary to "debug" and "replace before wearout". The result would be perfect reliability. Unfortunately these intermediate failures do exist as catastrophic or chance failures in the vital time period (tu) that lies between the time limits (td) and (tw), the useful region for component applications.

The obvious need, therefore, is to derive suitable engineering parameters which express the existence and magnitude of the "pure" random failure-rate characteristics. Most common electronic component families never reach the wearout condition within ordinary bounds of application, while other component families have decided wearout properties. It should be re-emphasized that all three phases of component failure must be taken into account. However, since the intermediate region has the most practical use in the engineering domain, it must be given prime consideration.[1]

---

1. In the case of missile electronic equipments, pre-launch observations to assure "debugging" and yet avoid "wearout" are aimed at guaranteeing the employment of the intermediate region (tu) as a composite but vital time-dependent characteristic of the complete system.

[redacted]

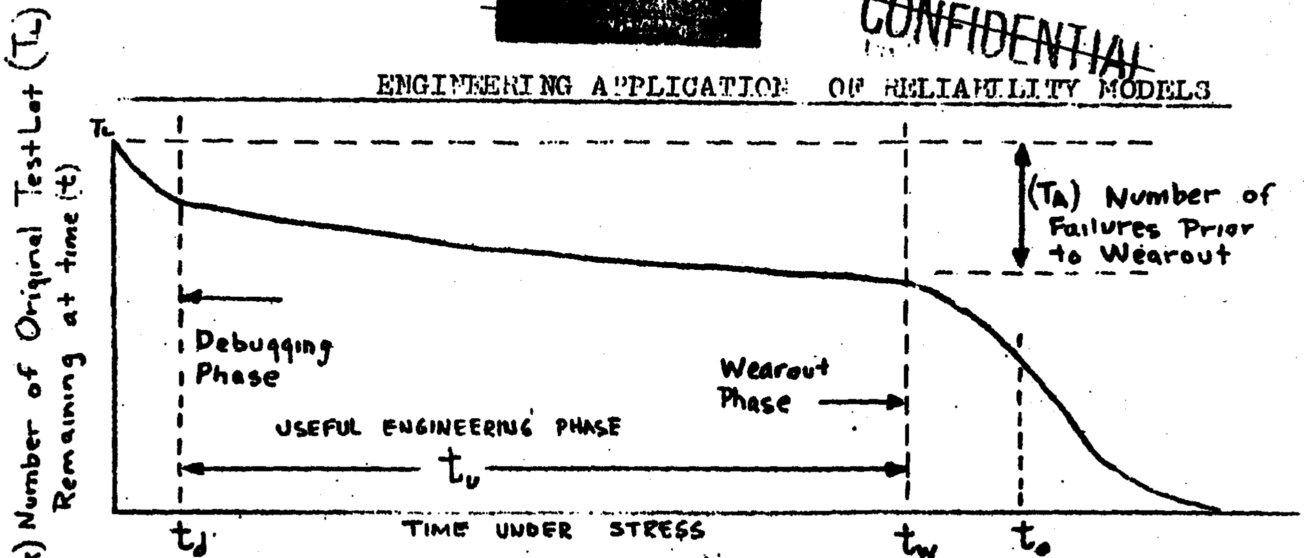


FIGURE 8-2A
ACCUMULATED FAILURES

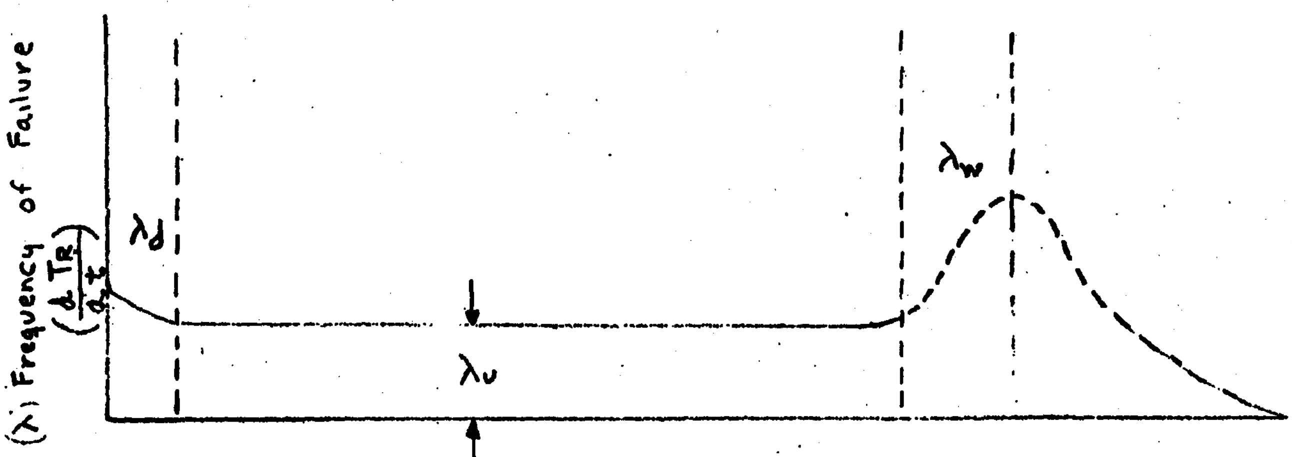


FIGURE 8-2B
FAILURE-RATE REGIONS

[redacted]

TABLE 8-1

Characteristics of Component-Part Families	Notation
(a) Useful Engineering phase sufficient to avoid wearout	$(\lambda_d + \lambda_u)$
(b) Neither wearout or debugging encountered in use	(λ_u)
(c) Debugged but wearout within practical limits	$(\lambda_u + \lambda_w)$
(d) All failure-rate phases are significant	$(\lambda_d + \lambda_u + \lambda_w)$
Unless otherwise noted Failure Rate normally refers to the λ_u phase	λ

Component parts can be classified in terms of the notation used in Figures 8-2A and 8-2B. For future reference, Table 8-1 summarizes this classification. Thus, a premium grade of debugged vacuum tubes would be classified as $(\lambda_u + \lambda_w)$; most capacitors and resistors would be classified as $(\lambda_d + \lambda_u)$ for use under environments encountered in most electronic packages. Special applications will require reconsideration of all such classifications.

One step beyond the "accelerated life" test is the "test-to-failure" program which has been particularly advocated by Robert Lusser.[1] A potential fallacy here is that the laboratory observations made are aimed at viewing the time (stress) position of (t_b), a characteristic of wearout, while in practical use the "pure" random phenomena of the intermediate (t_u) is the pertinent factor for most high-population components since they are classed as $(\lambda_d + \lambda_u)$ characteristic. Subjecting those components that are expected to experience severe environments to a test-to-failure program requires that one reassess the balance between pure random failures and wearout failures.

1. The inclusion of vacuum tubes is held in abeyance.

[redacted]

Looking further into the literature reveals voluminous data on the "life" characteristics of materials and components. These studies are predominantly analyses of the location of (t_o). Why is not the "pure" random characteristic reported upon in equal amount? The answer on an engineering plane is simple to find. The total failures that occur before wearout (T_A of Figure 8-2A) are usually discouragingly small for a suitable statistical analysis. Failure at the rate of 0.1 percent per 1000 hours or even 0.01 percent per 1000 hours within the (t_u) period, is often taken as a practical target. The testing of extreme quantities of test samples soon becomes prohibitive. A new criterion of failure-rate becomes necessary.

c. Mathematical Model. A practical hypothesis is required that will allow the use of test evidence in the (λ_w) phase to establish a guide to the prediction of (λ_u) or chance (catastrophic) failures. On a selective basis it is contended that this can be accomplished. One encouraging thought along this vein is provided by L. J. Berberich and T. W. Dakin[1] when they make the following observation about the testing of d-c paper capacitors:

> "In spite of the usual variations in leakage current during a life test .... where the current remains low during most of the life, indicating no gradual approach to failure, but only a sudden increase just before failure, it must be concluded that a reaction is occurring during this time."

Experimental data seem to support this argument that there is a continuity of failure-producing activity. This argument leads to the following practical hypothesis:

> Hypothesis 1 - For those components dependent upon a combined time-energy stress for failure production, there is a definite relation between the time of wearout failure and the "pure" or catastrophic failure rate prior to wearout.

1. Berberich, L.J. and Dakin, T. W. - "Part I: Guiding Principles in the Thermal Evaluation of Electrical Insulation", Insulation, Feb. 1956.

[redacted]

As a first application of this hypothesis two special cases are selected which have broad applicability, (1) the case of the thermal dissipator,[1] and (2) the case of the dielectric medium. In each instance the energy level of operation is a composite of electrical and thermal (environmental) stress. Thus, a second major hypothesis is proposed for guidance.

> <u>Hypothesis 2</u> - For those components of a thermally dissipative[2] or dielectric nature, there is a <u>linear</u> relation between the catastrophic failure rate (λ_u) and the time of wearout (t_w).

On the basis of these concepts it is possible to establish a simple theory of failure-rate prediction which can ultimately be put to the test of correlation with the physical facts in practical component applications.

Within the catastrophic-failure phase of a component's life, the "wearout" phenomena is said to occur in a random fashion. That is, only some random weak elements succumb to the normally low time stress condition. There is such a statistically large number of potential sources of weakness that the mathematical conditions of randomness appear to apply. (The interesting fact that a large number of failure sources can be visualized as having their individual wearout phenomena located at random times, gives rise to the concept that such a condition would appear as a series of catastrophics in any practical test lot. It is only when a large number of samples succumb from the <u>same</u> mechanism that a group wearout is observed). Thus, within the useful period of component life (t_u), a component will survive according to the relation

$$Ps = e^{-\lambda t}$$

where Ps = probability of survival

t = any time after t_o and before tw

λ = catastrophic failure rate

---

1. The inclusion of vacuum tubes is held in abeyance.
2. Excluding vacuum tubes.

In the conduct of the first experiment if should be remembered that the normal practice is not to replace any failed component from the original test lot of (T_L) with a new test sample. Thus, the test lot diminishes exponentially within the (t_u) period. A hypothetical definition of the "mean life" (m) of the test sample is the time at which 37 percent of the test samples (at t_d) remain. (The Ps for any sample is $1/e$ which makes $t\lambda_u$ equal to unity). Thus $m = 1/\lambda u$. It should be remembered, however, that the actual reduction of the test lot to 37 percent as a result of catastrophics alone is practically never observed in an actual case. Thus, component "mean life" must be interpreted with caution. Interpreted simply as the reciprocal of λ_u little error can be incurred when talking about component part test evidence. When applied to complex systems the term "mean life" can have additional significance.

d. Physical Uncertainties. In the area of component testing, uncertainties arise from the use of compromise measurement and test methods, the choice of sampling plans, the incomplete separation (as observables) of catastrophic and performance-degradation failures, complexities of the basic component design, limitations of data analysis methods, the practical lot discontinuities expected from production quantities of parts, etc. Despite these contingencies experience has indicated that within the bounds of practical observables, it is possible and fruitful to synthesize valid component failure-rate information in a form suitable for application to complex electronic systems.

When a complex electronic system is placed into operation following its correct assembly, the equipment, normally undergoes a debugging period similar to that of component test groups. The debugging process reveals early performance inadequacies which are ameliorated by appropriate realignment. Outages occur during the debugging process as the result of chance (catastrophic) failures requiring equipment shutdown and repair. Only the chance failures are usually taken as evidence of debugging although it should be noted that a performance "shake-down" is normal and that gross misalignment may cause secondary catastrophic failures. After this period the equipment settles down to a sustained characteristic failure-rate characteristic, which (according to the simple mathematical model of reliability) is just the sum of the individual rates (λ_u) for all of the "series type" component parts in the equipment.

If a typical equipment were observed within its post-debugging period only the passage of time and occurrence of outages could be recorded as significant catastrophic-failure information. Figures 8-3A and 8-3B illustrate this kind of data. Failures occur and after some reasonable total operating time an average failure-free period (mean-life) can be calculated. Comparing the results from two equipments (viz. Figures 8-3A and 8-3B) it can be concluded that the equipment with the longer "mean life" is superior. If the equipments are to operate for long periods, the better unit (Figure 8-3A) would definitely require less maintenance, maintenance cost and down time. Furthermore, if the equipments are to be sent on a mission of duration Δt the better equipment would provide a better probability of success than would the inferior equipment.

The important new factor here is the indication that the starting of the mission period Δt is itself random. Even if the mission period Δt is less than the equipment mean life, there is still a sizeable probability that a failure will occur. This is illustrated in Figure 8-3A. For the same mission period, the superior of the two equipments (on the basis of mean life) is still comparatively superior as seen in Figures 8-3A and 8-3B.

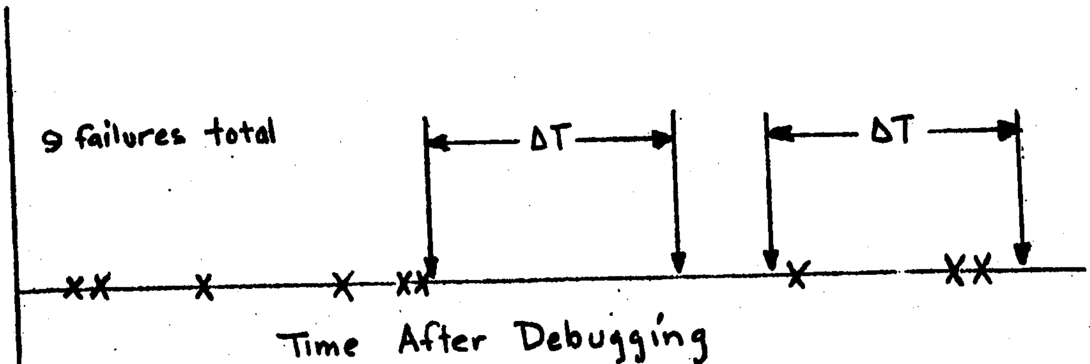


FIGURE 8-3A

Failure Data, Better Equipment

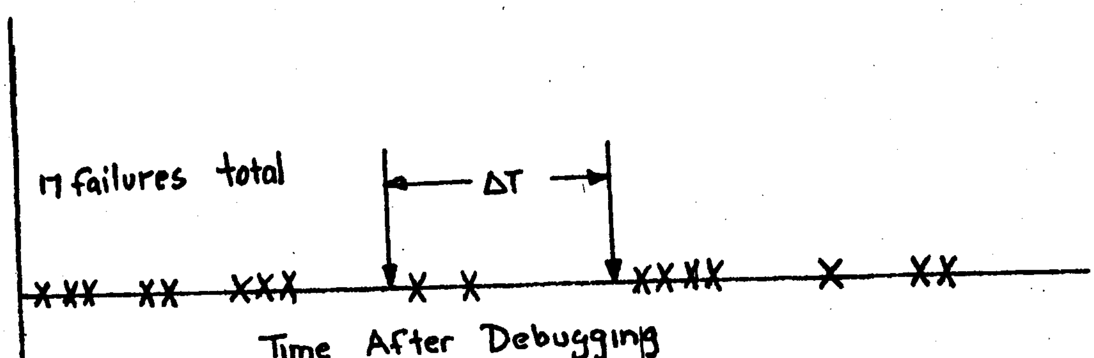


FIGURE 8-3B

Failure Data, Inferior Equipment

If an equipment is to be a "one-shot" device (a missile for example), a comparison on the basis of mean life is still valid <u>if</u> operation is assured between bounds of debugging and wearout.

For a mission period (Δ t) equal to the mean life (m) of an equipment,

$$P_s = e^{-\frac{\Delta t}{m}} = \frac{1}{e} \cong 37\%$$

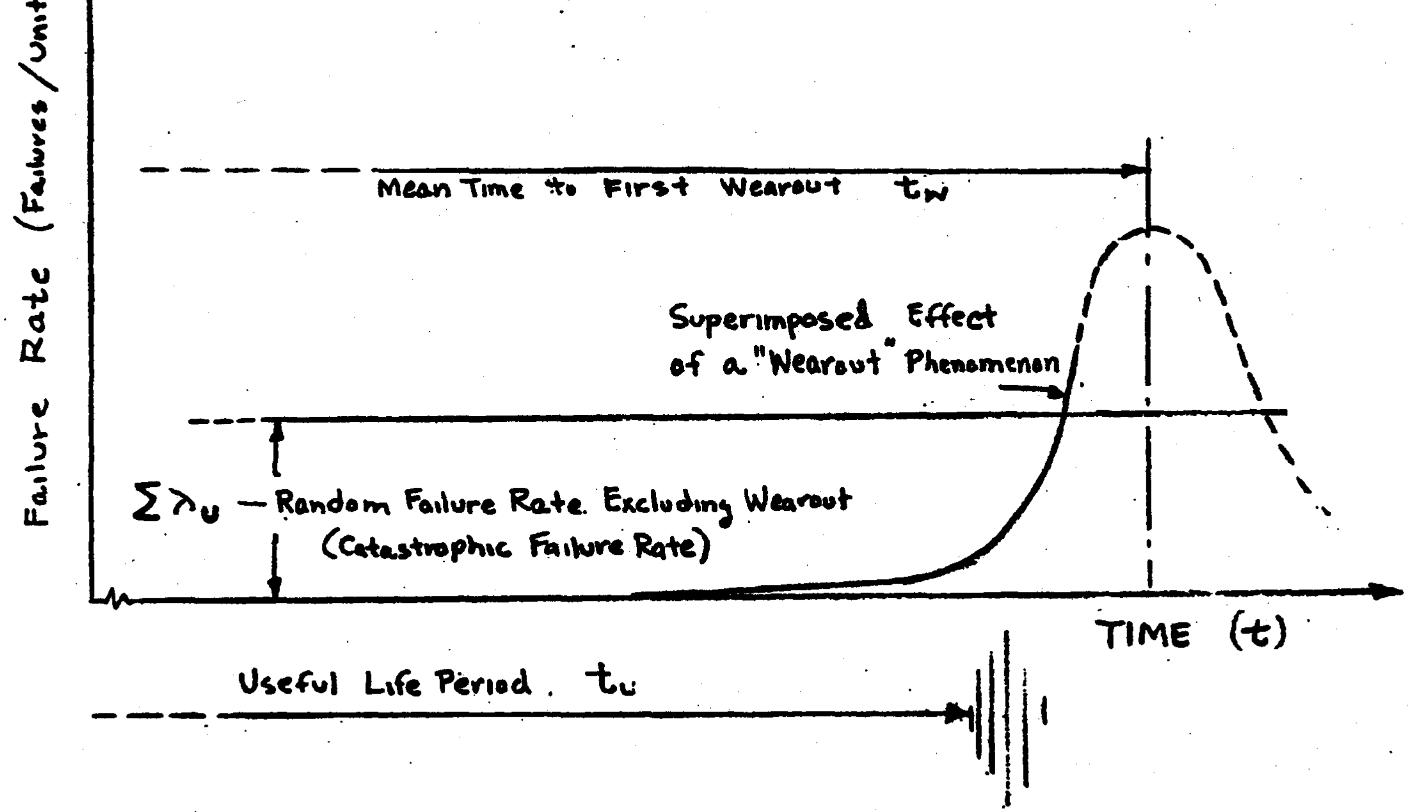
Thus, under these conditions, if a large number of equipments were employed to accomplish the same mission, only 37 percent would be operative at the close of the mission. It can only be concluded that for high probability of tactical success, either (1) the mission period should be kept small compared with equipment mean life or (2) the total number of equipments operating in the field should be increased.

An interesting and vital analysis must be applied to a system which is of a "one-shot" nature and employs a key series type of component which degrades (on a statistical basis) and establishes the expected total life of the system. Under these conditions the probability of survival from wearout must be combined with the probability of survival from catastrophics to establish a significant time boundary. Figure 8-4 shows that once the wearout region is reached it is meaningless to consider the probability of survival from catastrophic (chance) failures. However, the probability of <u>reaching</u> the over-riding wearout time remains a significant factor.

These facts must be stressed in concluding this outline of the catastrophic-failure analysis of electronic system reliability: Catastrophic failure analyses form a valid index of reliability contingent upon the achievement of optimum performance through careful design, analysis and redesign to minimize the chance of wearout failures. Thus, the catastrophic failure characteristics of a system form a practical target

FIGURE 8-4

WEIGHING THE RELATIVE SERIOUSNESS OF RANDOM (CHANCE) FAILURES AND THE MORE-PREDICTABLE "WEAROUT" FAILURES.



CRITERION:

Probability of Survival $P_s \cong e^{-t\Sigma\lambda_u}$

where: $t_d < t < t_u$ (t_d = debugging time)

and $t_u \cong t_w$

of design and a comparative measure of the actual and potential state of the art.

3. Key Definitions and Nomenclature for Reliability Engineering

The following definitions are considered basic to the field of electronic system reliability. In selecting these vital terms, all efforts have been made to "human engineer" their phraseology and sequence so that the design engineer will have access to a rapid and sufficient indoctrination to meet his practical needs.

1) Reliability Engineering: This identifies an engineering discipline aimed at the study and achievement of failure-free operation of (electronic) equipments.
2) Reliability: A beneficial characteristic of electronic equipment produced by design, manufacturing, operating and maintenance methods which minimizes system outages and maximizes the chances of successful operation during critical periods of usage.
3) Probability of Survival: A numerical expression of reliability, with the accepted nomenclature of P_s and a range from 0 to 1.0 indicating the extremes of "impossibility" and "perfection".
4) Exponential Failure Law: The statistical characteristics of an equipment or group of test specimens, expressing the fact that the next decremental P_s, (dP_s) at any time t over an interval (dt) is proportional to the P_s at that time. This gives rise to the accepted expression

$$P_s = e^{-\lambda_u t}$$

(λu being a proportionality constant referred to as failure-rate) which is valid within certain practical engineering limits. Under those conditions where a failure-rate parameter λ_u can be proven valid both for the conditions of component-part testing and for application in complete equipments, the failure rate for the equipment is the sum of the part failure rates.

$$\lambda_u \text{ (equipment)} = \sum \lambda_u \text{ (parts)}$$

and $P_{(s)}$ equipment $= P_{(s)1} \; P_{(s)2} \; P_{(s)3} \cdots$ etc.

$$= \pi \, P_{(s)}$$

5) Component Part: An electronic component part is a circuit element or other fabricated unit not normally subject to disassembly. Examples of these are capacitors, resistors, tubes, gear boxes, etc. There are two basic categories of "components" often referred to as (1) parts-peculiar (low-population parts possibly unique to a given equipment) and (2) parts-general (high-population parts with essentially universal usage in electronic design).

6) Failure Rate: This numeric expresses the frequency of failure occurrence which can be observed over specified time intervals when observing equipments or component parts. This parameter (λ_u) obeys the exponential failure law when the occurrence of failures is random in the time domain.

7) Catastrophic (Chance) Failures: Such failures are those which occur within the operational time period after all efforts have been made to eliminate design defects and unsound components, and before any foreseen "wearout" phenomena have time to appear. For example, the random "open" occurring in a resistor wire after several hundred hours of operation. Or, as a more subtle example, the rare degradation of transconductance in a vacuum tube at a statistically early time.

8. Performance Degradation (Wearout) Failures: In addition to the catastrophic failure of component parts or systems, the initial performance of circuitry or mechanisms tends to degrade with time. The performance degradation of such elements as vacuum tubes, batteries, bearings, etc., is subject to anticipation and usually can be circumvented by preventive maintenance. For the purposes of definition, performance degradation failures are those that can be avoided by appropriate preventive maintenance based upon the best engineering prediction of the wearout probability distribution.

9. Mean Life: The mean life of a complex system (in which failed parts are replaced with new parts of equal failure rate) is essentially the average time between outages caused by catastrophic failures. The mean-life characteristic of a group of similar test specimens all subject to the same stress conditions (where failed components are not replaced) is subject to a twofold definition. In the case of wearout phenomena the mean life describes the time at which a test group displays a maximum frequency of failure. This assumes few individual catastrophic failures prior to the existence of the principal group failure-distribution function. In the case of catastrophic failures, the mean life is the time at which 37 percent of the test specimens survive, assuming wearout is never reached. For the sake of clarity, the catastrophic mean-life is defined as random mean life and the wearout mean-life is defined simply as group mean life. In engineering practice, group mean life increases with improved circuit design and system maintenance, while the random mean life increases mainly through improved component selection and application. Within practical bounds of time before wearout, the observed random mean life is equal to the reciprocal of the failure rate for component test groups or complete equipments. In

general, less than 5 percent of the equipment operational failures are attributable to other than catastrophic failures in well-designed electronic systems. For this reason, reliability is usually measured in terms of the random mean life where occasional group failures appear as indistinguishable contributions to the total.

10) Debugging: This is the process of engineering "shakedown operation" performed as a means of eliminating system elements and circuits (proven incompatible with environmental and functional needs) by producing early failures. The weak or over-stressed elements are caused to fail and replaced by elements which are (statistically) of a normal quality not subject to a similar failure. The time necessary to weed out these early failures depends upon the total number of them in the equipment package, the quality of parts used, and upon the ultimate irreducible failure rate of the equipment. Debugging time seems to be controlled by the fact that the original defectives reduce to $1/e$ of their original number in about 25 hours of operation, assuming all component over-stressing has been alleviated.

11) Independent Failures: In the definition of the exponential failure law it is essential to assure that each source of potential failure be capable of causing the complete malfunction of the equipment under consideration. In electronic systems, signals are usually cascaded and power sources are non-redundant so that nearly all component parts introduce independent sources of catastrophic failure. Such independent failures are, therefore, the normal occurrence rather than the exception.

12) Component Stress: The stresses on component parts from the reliability viewpoint are those factors of usage (or test) which tend to affect the failure rate of these parts. This includes voltage, power, temperature, frequency, rise time, etc. However, the principal non-electrical source of stress is usually the thermal-environment stress.

13) Safety Factor: There is usually a limiting stress (or combination of stresses) at which part failure rate goes to infinity or to an unacceptable extreme. The degree to which application-stress conditions are below such a limit constitutes a safety factor from the catastrophic-failure viewpoint. From the performance degradation viewpoint a safety factor is represented by an adequate reserve of energy (as in the case of a battery), gain characteristic (transconductance), bandwidth, or other essential performance factor. Other types of reliability safety factors are to be found in the areas of maintenance, human engineering of control panels, etc. From the operations viewpoint safety factors may be represented by weight reduction, minimum supply of cooling air or equipment redundancy. Thus, it is necessary to recognize that there is a "trade-off" between safety factors to achieve the optimum overall design, i.e. one which has realistic safety factors in contrast to the design with overly generous safety factors.

In planning the application on component parts it is necessary to appreciate that there is usually a residual failure-rate arising from the parts manufacture, handling and insertion, which cannot be reduced by derating. Realistic safety factors allow a reasonable chance of failure above this residue level. Such safety factors allow the equipment to operate in the regions required for it to fulfill its functions but do not subject the equipment to any severe stresses.

B. RELIABILITY STRESS ANALYSIS OF ARS COMPONENT PARTS

1. Introduction

The stresses applied to a component part in its ultimate circuit and physical position constitute a complex "force function" while the inherent reliability parameters of the components can be thought of as "transfer functions". These transfer function characteristics must be reduced to equivalent failure-rate statistics applicable over the practical time range of (1) usage contemplated, or (2) usage specifically provided in the final electronic packages. For this study all subsequent failure rates will be of the λ_u category unless otherwise stated. It should be re-emphasized that this is the practical region of utility and is contingent upon appropriate debugging practices and avoidance of wearout where engineering control permits. (Where wearout cannot be avoided, superposition of wearout must be taken into account according to the concepts of Figure 8-4).

High-population parts common to modern electronic design are most probably applicable to the ARS circuitry and packaging. The early vehicles will employ a higher percentage of standard items, i.e. those parts not specifically designed for ARS. With experience, new facts about the ARS environment will dictate areas where the risk of employing such new and unproven parts will be compensated by their fundamentally improved reliability or performance. The magnitude of such tailored-part populations can be expected to grow through the various stages of ARS growth. For this analysis it will be assumed that such new families of parts will be integrated into the "packet" of component families available at any given stage of growth. Thus, a total of three sets of failure-rate prediction curves have been prepared to extrapolate the ARS resources of reliability from the viewpoint of available parts and part application techniques. Each set of data corresponds to an ARS growth stage. Each set of data is a summary of predicted failure-rates that takes into account the availability of new materials, the potential improvements from quality control and/or selection techniques, contemplated packaging methods, the potential success inherent in reducing handling hazards, and the other programs of reliability improvement covered in more detail in other paragraphs.

For this analysis, the high-population parts of the ARS are outlined in Table 8-2. This table refers to Figures 8-5 through 8-28 which are the specific failure-rate prediction characteristics derived for the given component family and ARS growth stage. These in turn are a summary of many deliberations. For example, many of these prediction curves show a temperature asymptote, i.e. a bounding temperature at which failure-rate tends toward infinity or total unacceptability. In going from one growth stage to the next, the predicted availability of new materials or material processing is reflected as a new asymptote, usually at a substantially higher temperature. Also, it can be noted that most prediction curves show a tendency to "flatten out" at low stress levels. That is, there is a residue of failure-rate which is beyond reduction by derating or use at low combined stress levels. This may be interpreted as the hazard of manufacture, transport, insertion (including soldering) and random stress conditions (such as shelf life effects, severe humidity effects, chance excursions into temperature extremes, etc.) Much can be done to reduce these sources of component failure. Such improvements are also projected into the failure-rate prediction curves.

TABLE 8-2

Families of High-Population Component Parts in ARS

Component Family[1]	ARS Growth Stage[2]		
	#I	#II	#III
1. Capacitors, Paper Dielectric	Fig. 8-5	Fig. 8-6	Fig. 8-7
2. Capacitors, Mica Dielectric	Fig. 8-8	Fig. 8-9	Fig. 8-10
3. Capacitors, Ceramic	Fig. 8-11	Fig. 8-12	Fig. 8-13
4. Resistors, Composition, Fixed (or film)	Fig. 8-14	Fig. 8-15	Fig. 8-16
5. Resistors, Wire Wound	Fig. 8-17	Fig. 8-18	Fig. 8-19
6. Transformers and Coils	Fig. 8-20	Fig. 8-21	Fig. 8-22
7. Relays and Switches	Fig. 8-23	Fig. 8-24	Fig. 8-25
8. Diodes, Silicon	Fig. 8-26	Fig. 8-27	Fig. 8-28

1. It is to be noted here that the classification of component families is only representative, i.e. in going from Growth Stage I to Growth Stage III the "paper capacitor" family may actually employ a new dielectric material other than paper. However, the circuit demands will be essentially the same and the "paper substitute" characteristics can be projected into equivalent ranges, tolerances and other application needs.

2. It is pertinent to note here that these reliability growth stages correspond to the development phases of ARS (described in the Development Plan submitted by RCA) according to the following approximate relation:

Growth Stage I	- ARS Development phases 1 and 2
Growth Stage II	- ARS Development phases 3 and 4
Growth Stage III	- ARS Development phases subsequent to 4

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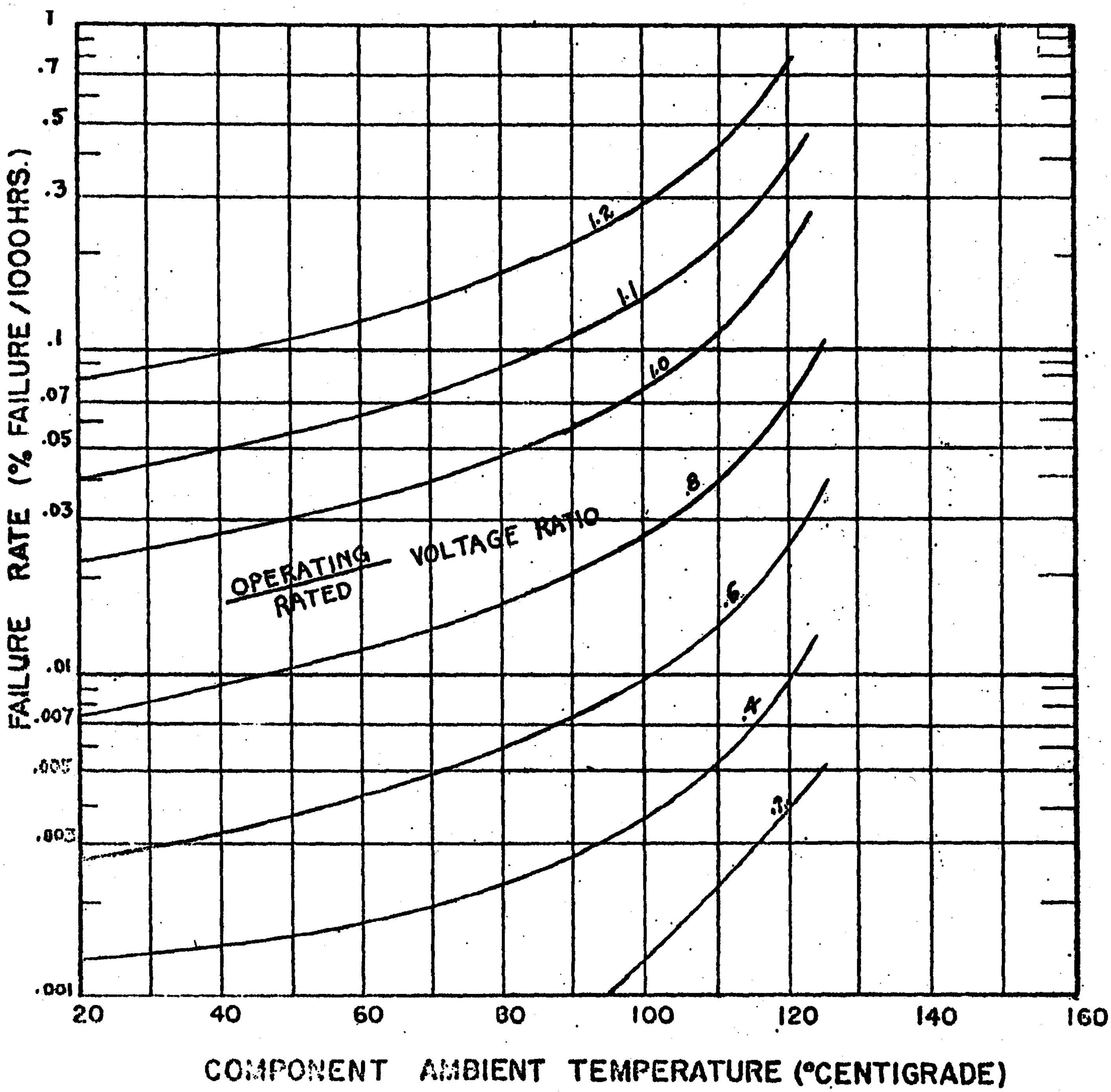

Figure 8-5

PREDICTED FAILURE RATES FOR PAPER CAPACITORS

ARS GROWTH STAGE I

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[redacted]

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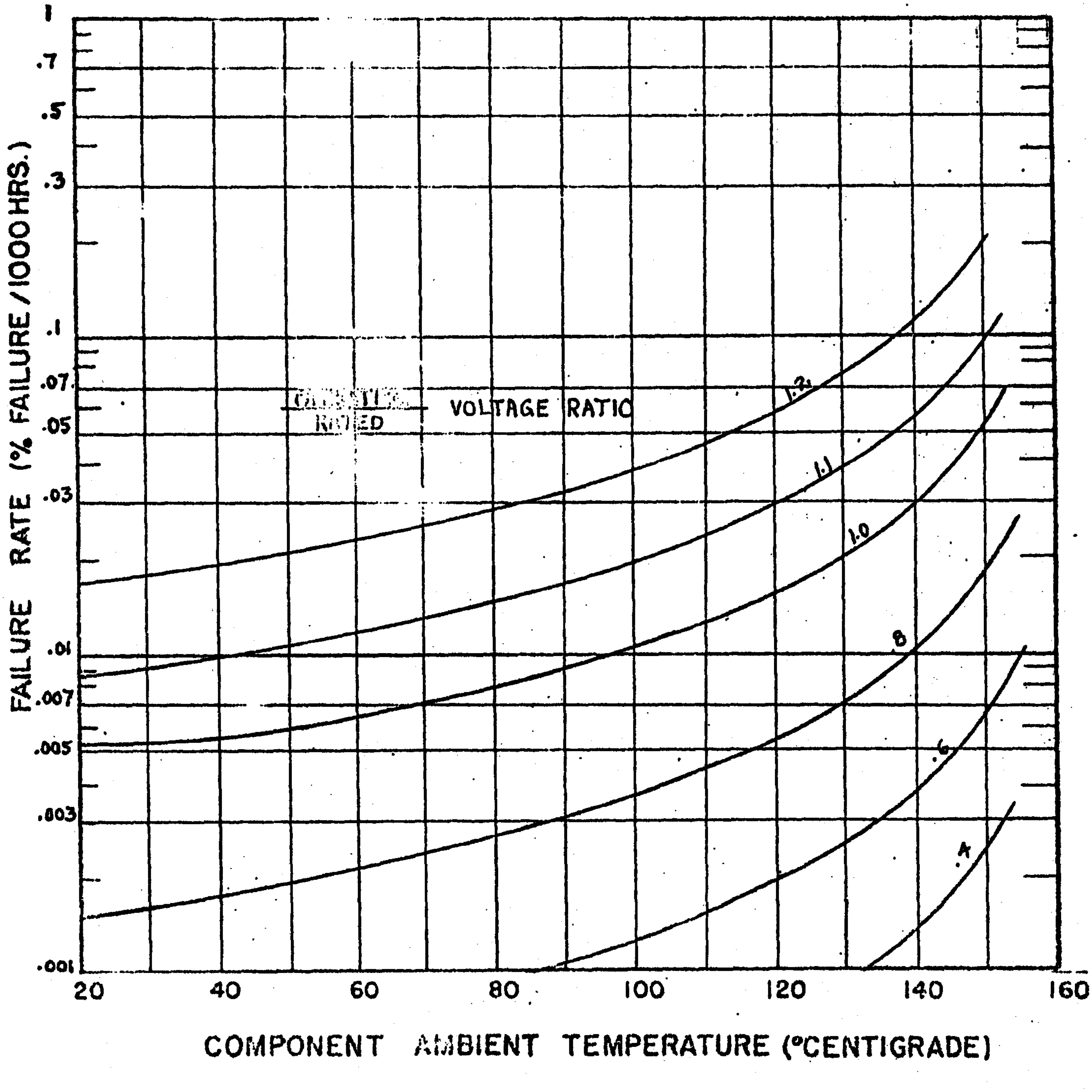

Figure 8-6

PREDICTED FAILURE RATES FOR PAPER CAPACITORS

ARS GROWTH STAGE II

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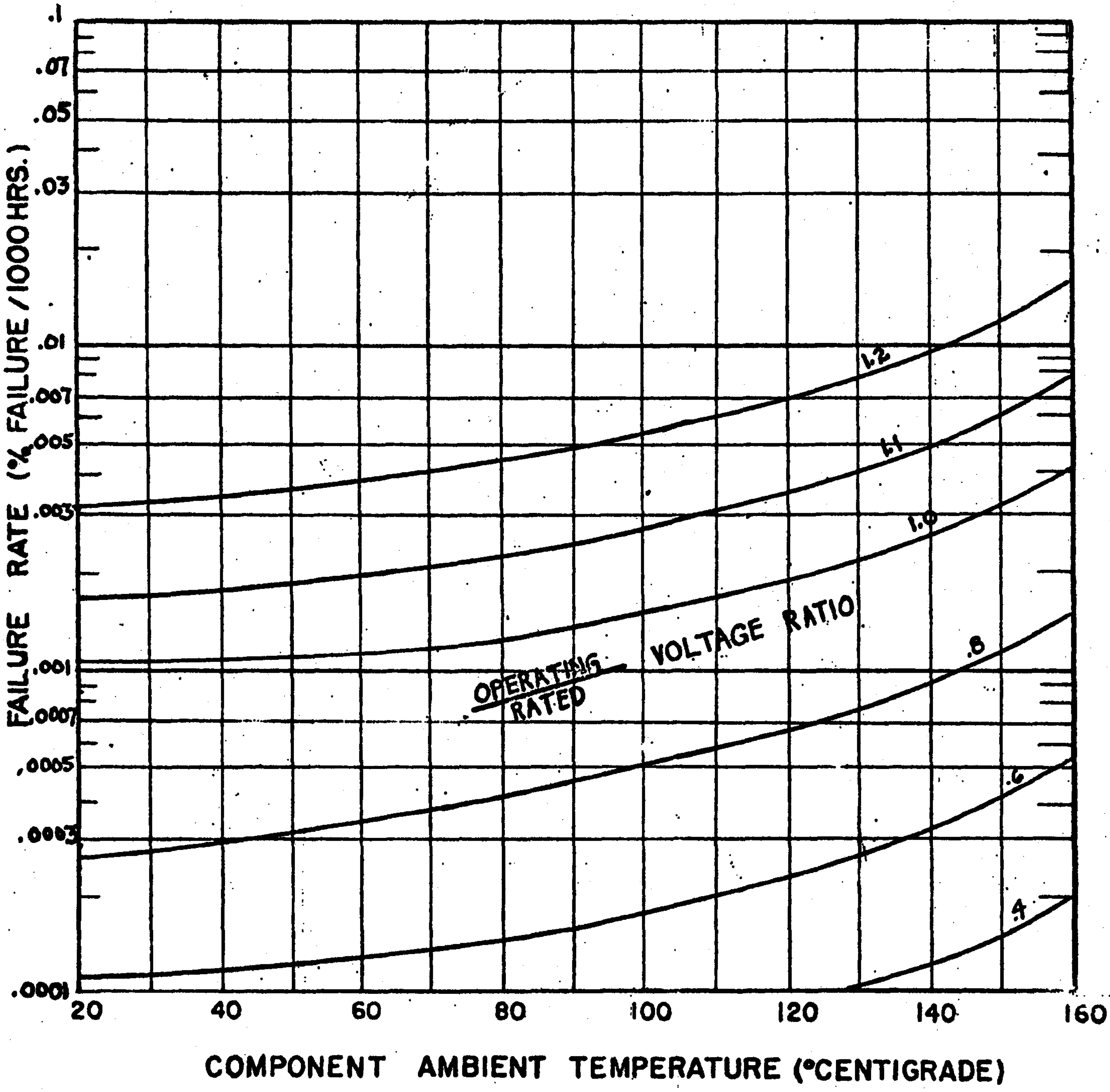

Figure 8-7

PREDICTED FAILURE RATES FOR PAPER CAPACITORS

ARS GROWTH STAGE III

[redacted]

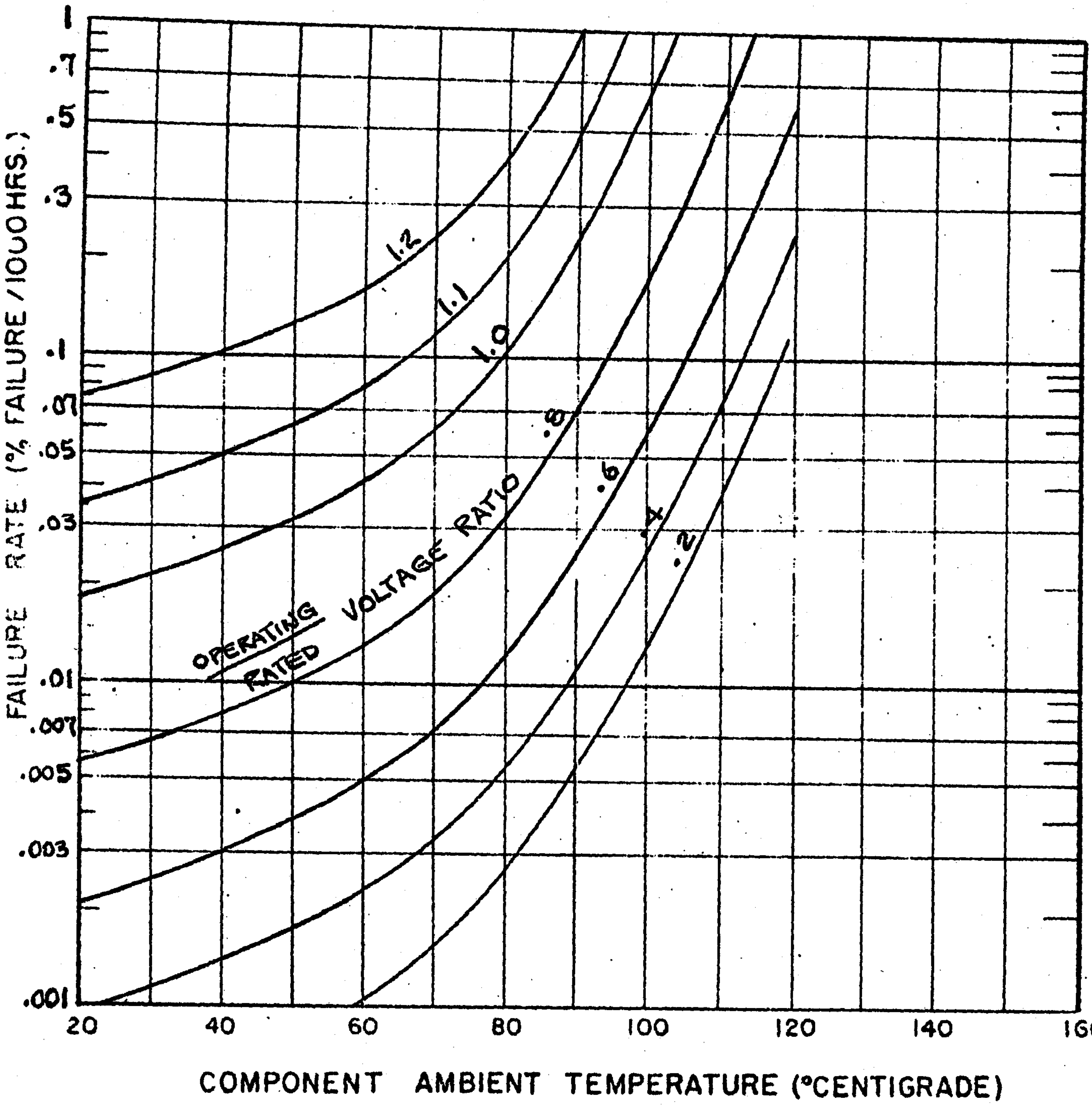

Figure 8-8

PREDICTED FAILURE RATES FOR FOIL MICA CAPACITORS

[redacted]

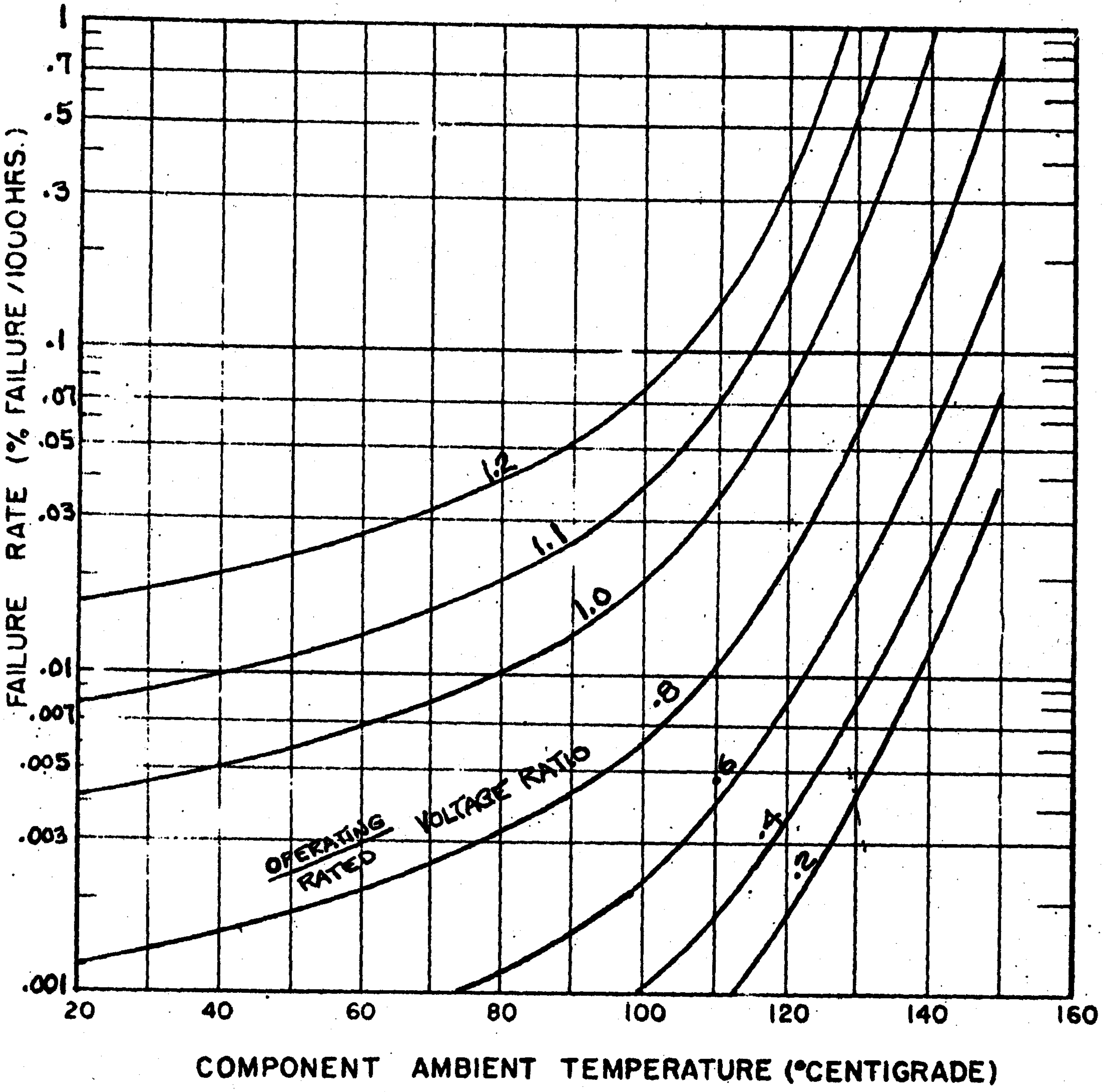

Figure 8-9.

PREDICTED FAILURE RATES FOR FOIL MICA CAPACITORS

ARS GROWTH STAGE II

[redacted]

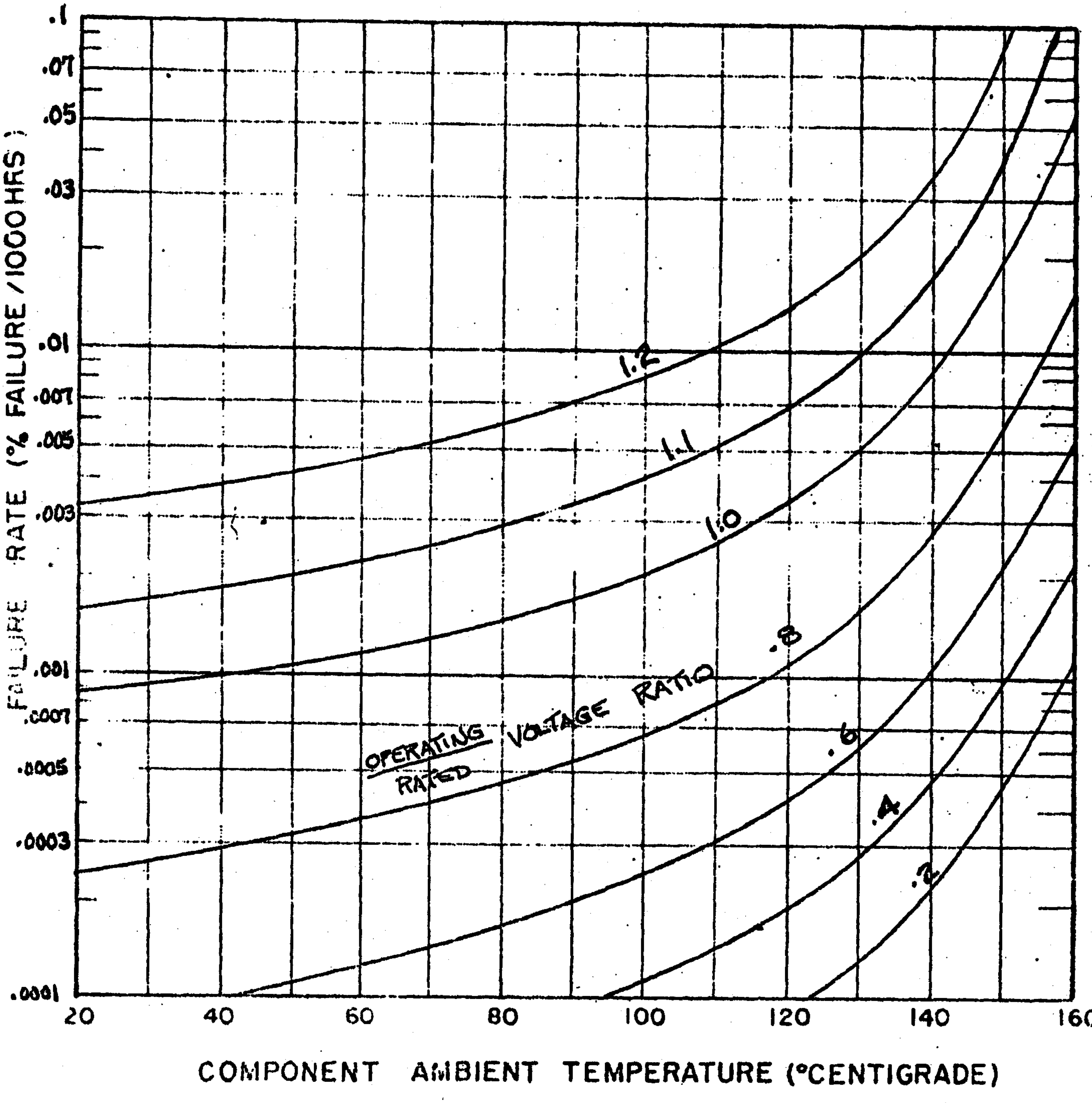

Figure 8-10

PREDICTED FAILURE RATES FOR FOIL MICA CAPACITORS

CONFIDENTIAL

ARS GROWTH STAGE III

[redacted]

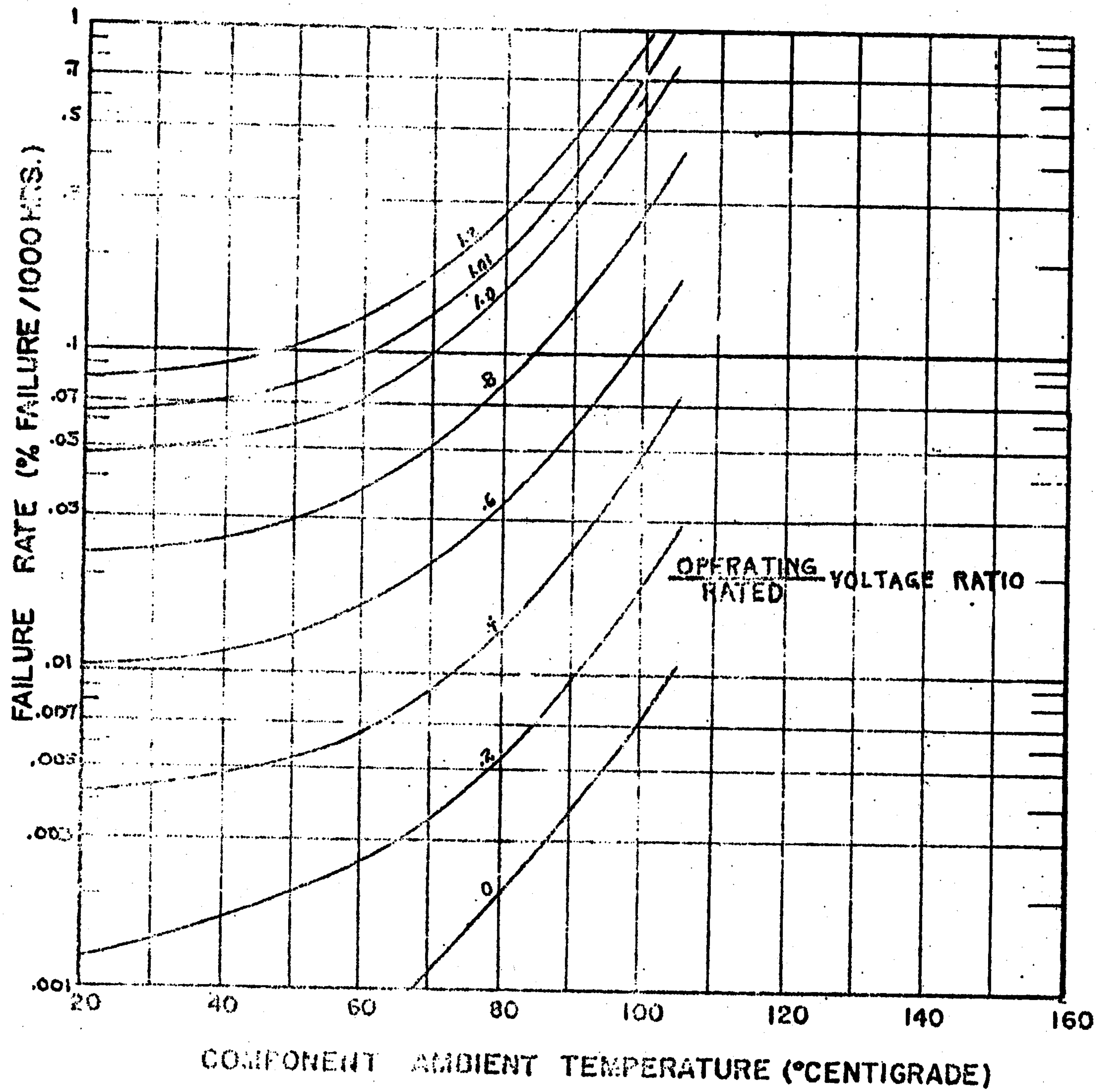

Figure 8-11

PREDICTED FAILURE RATES FOR CERAMIC CAPACITORS

ABS [illegible]TH STAGE I

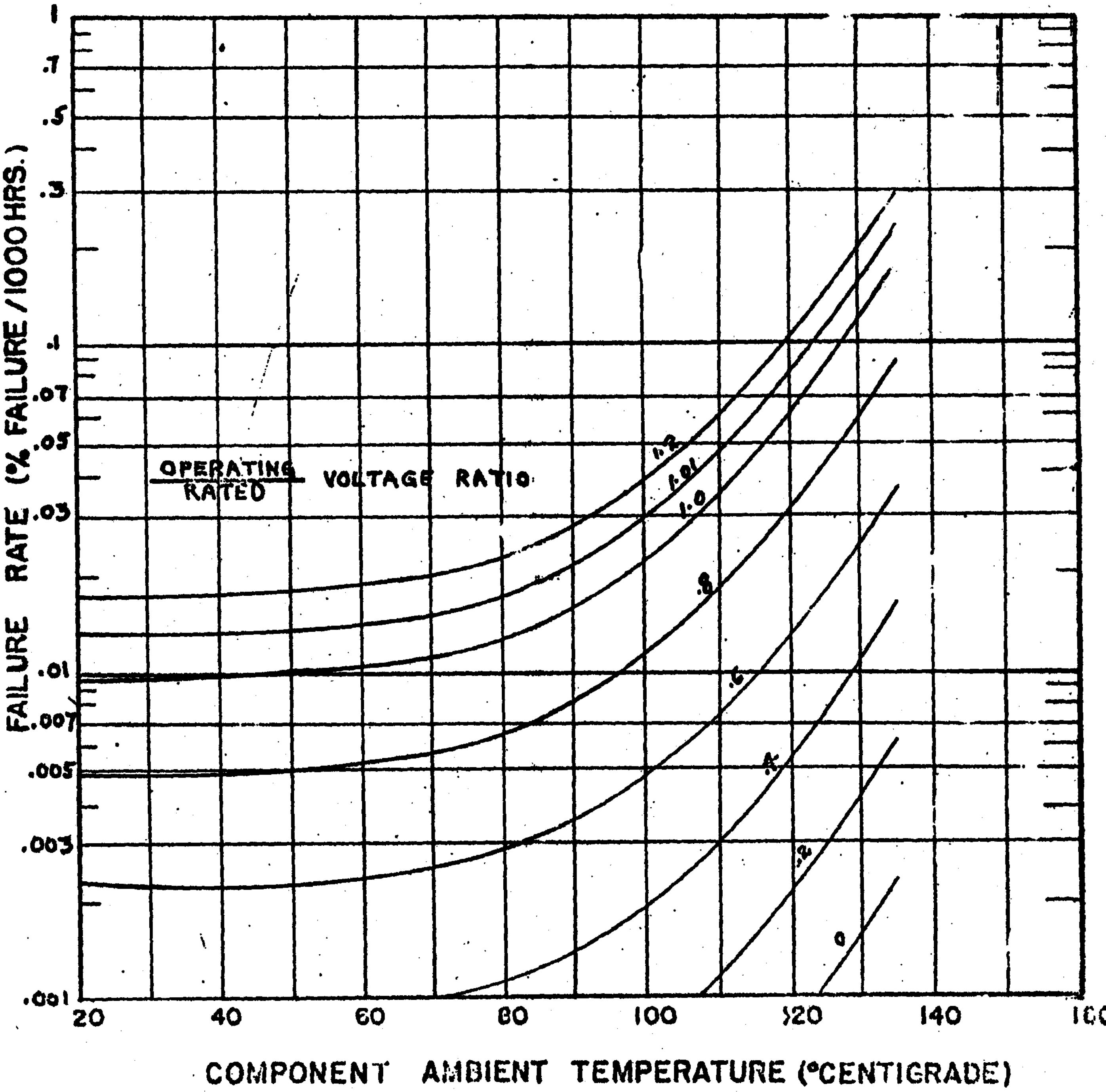

Figure 6-12

PREDICTED FAILURE RATES FOR CERAMIC CAPACITORS

ARS GROWTH STAGE II

[redacted]

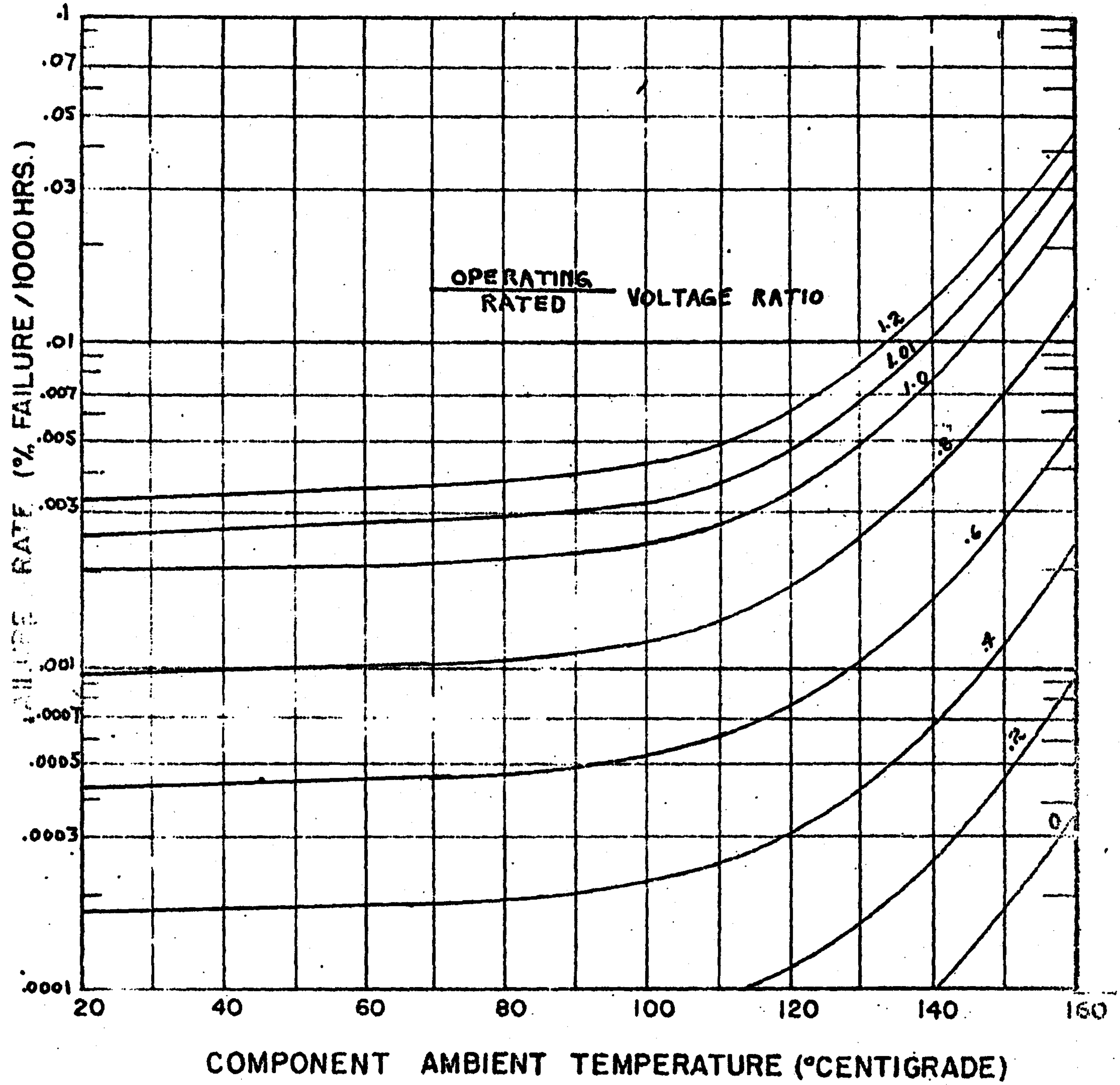

Figure 8-13

PREDICTED FAILURE RATES FOR CERAMIC CAPACITORS

ARS GROWTH STAGE III

CONFIDENTIAL

[redacted]

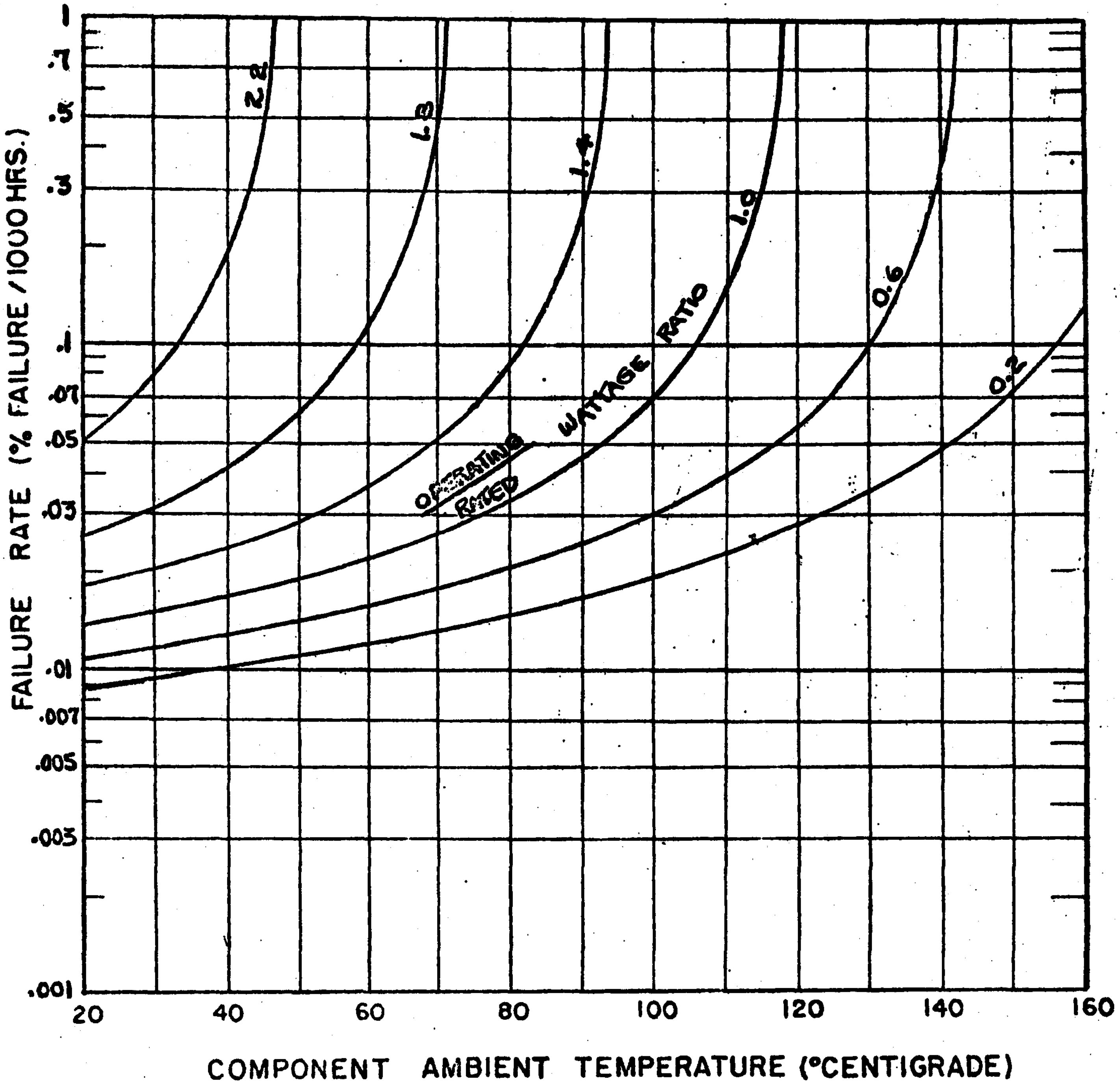

Figure 8-14

PREDICTED FAILURE RATES FOR COMPOSITION RESISTORS

[redacted]

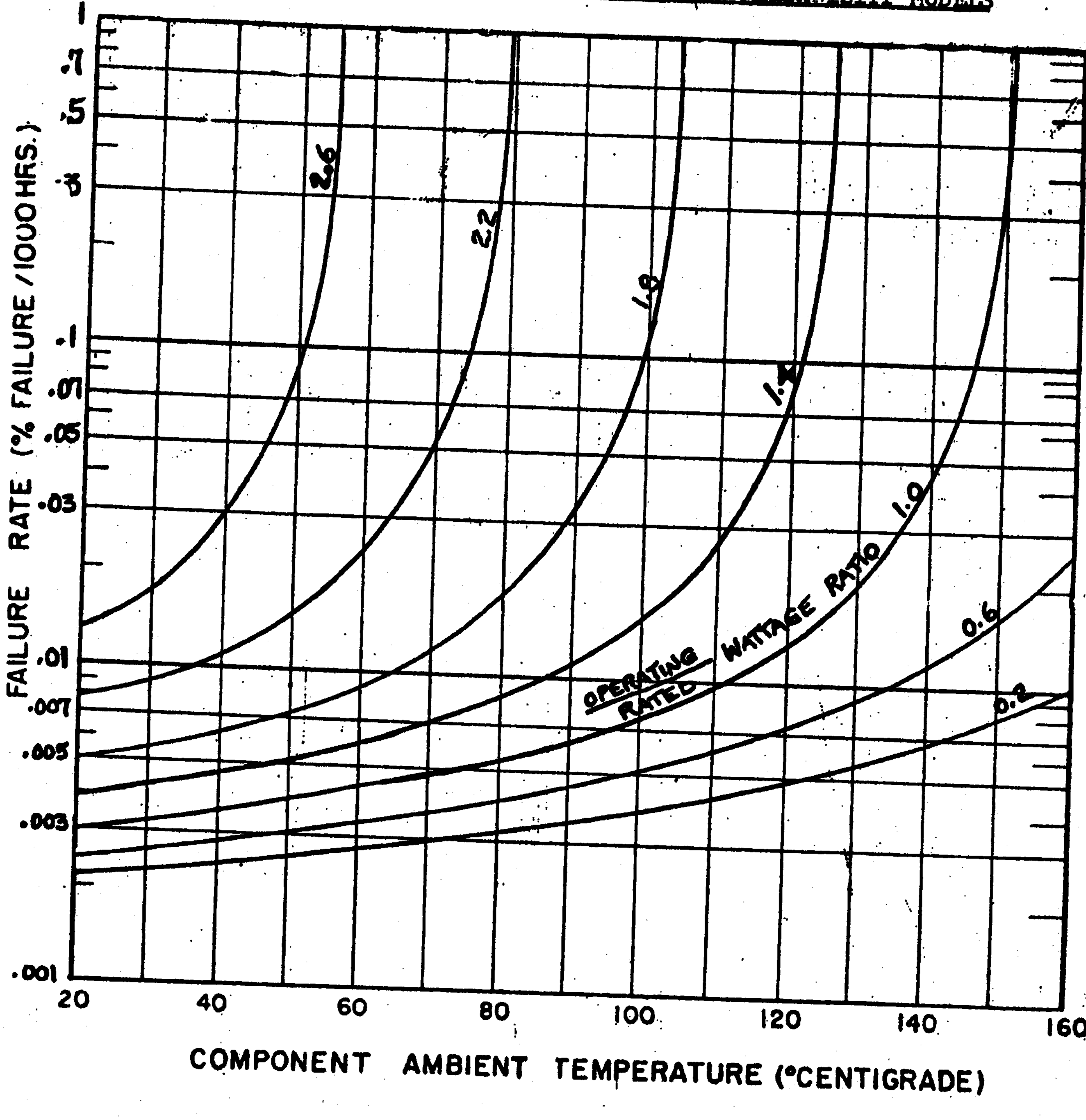

Figure 8-15

PREDICTED FAILURE RATES FOR FILM RESISTORS

ARS GROWTH STAGE II

[redacted]

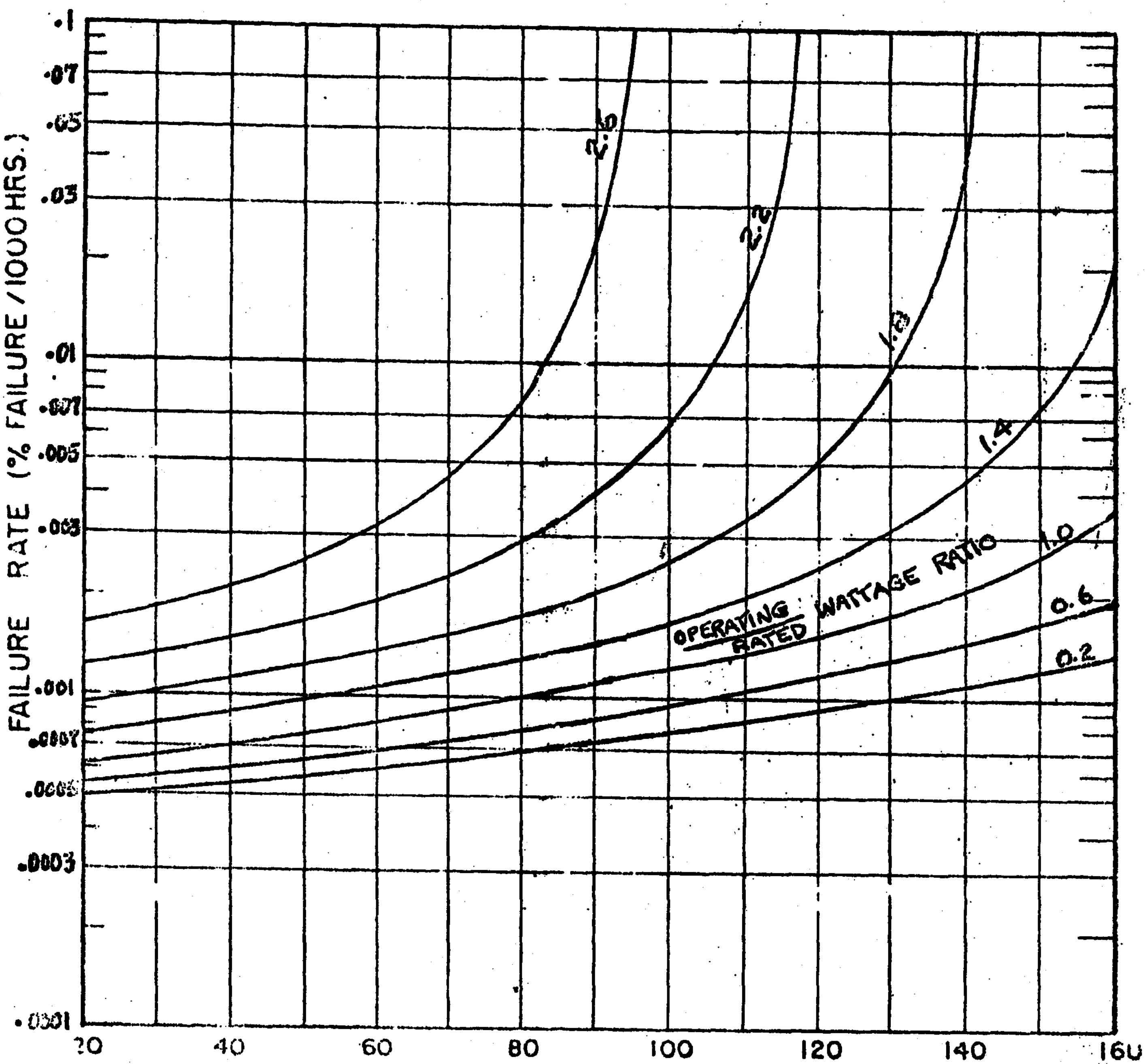

Figure 8-16

PREDICTED FAILURE RATES FOR FILM RESISTORS

[redacted]

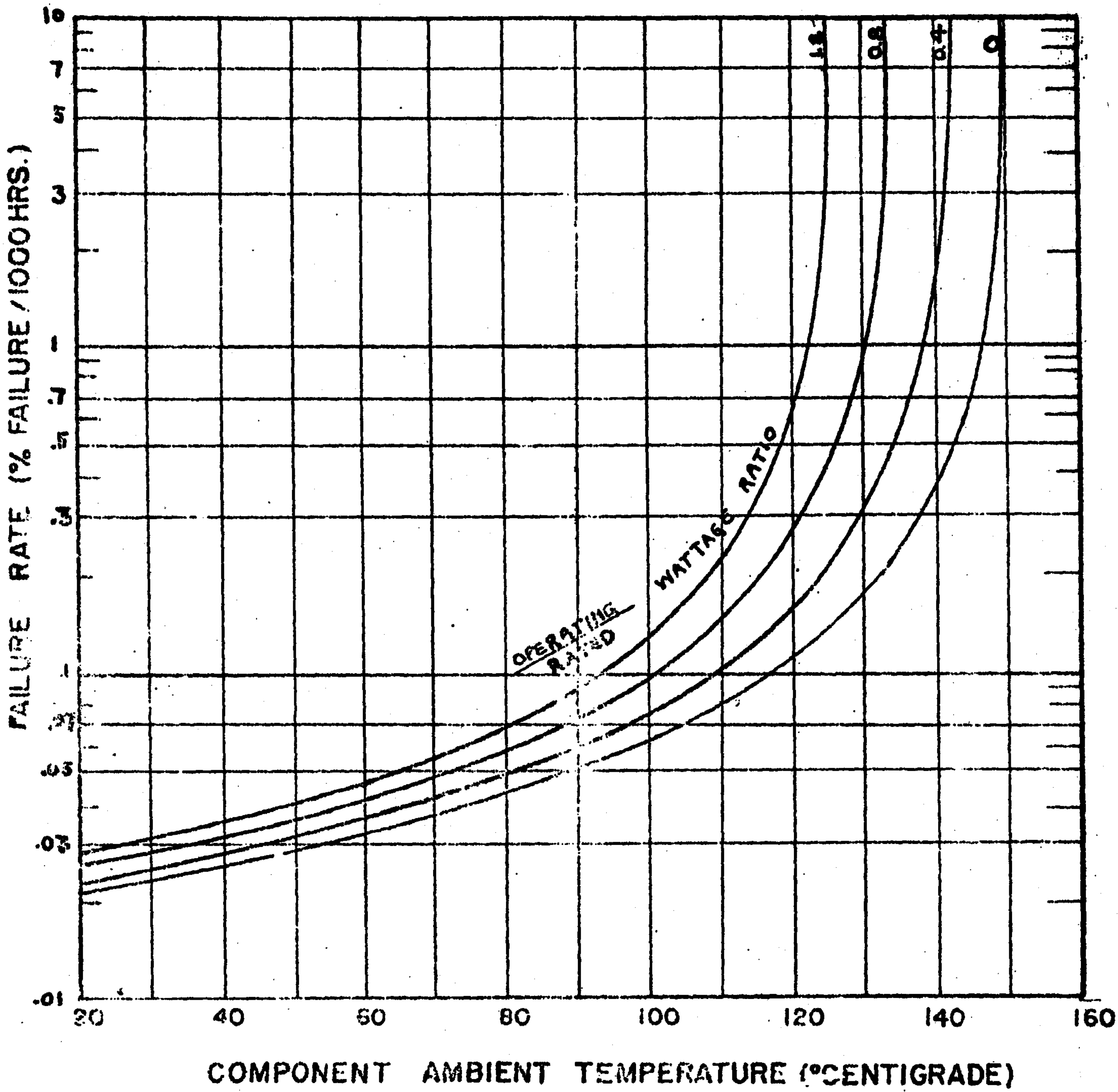

Figure 8-17

PREDICTED FAILURE RATES FOR ACCURATE WIREWOUND RESISTORS

[redacted]

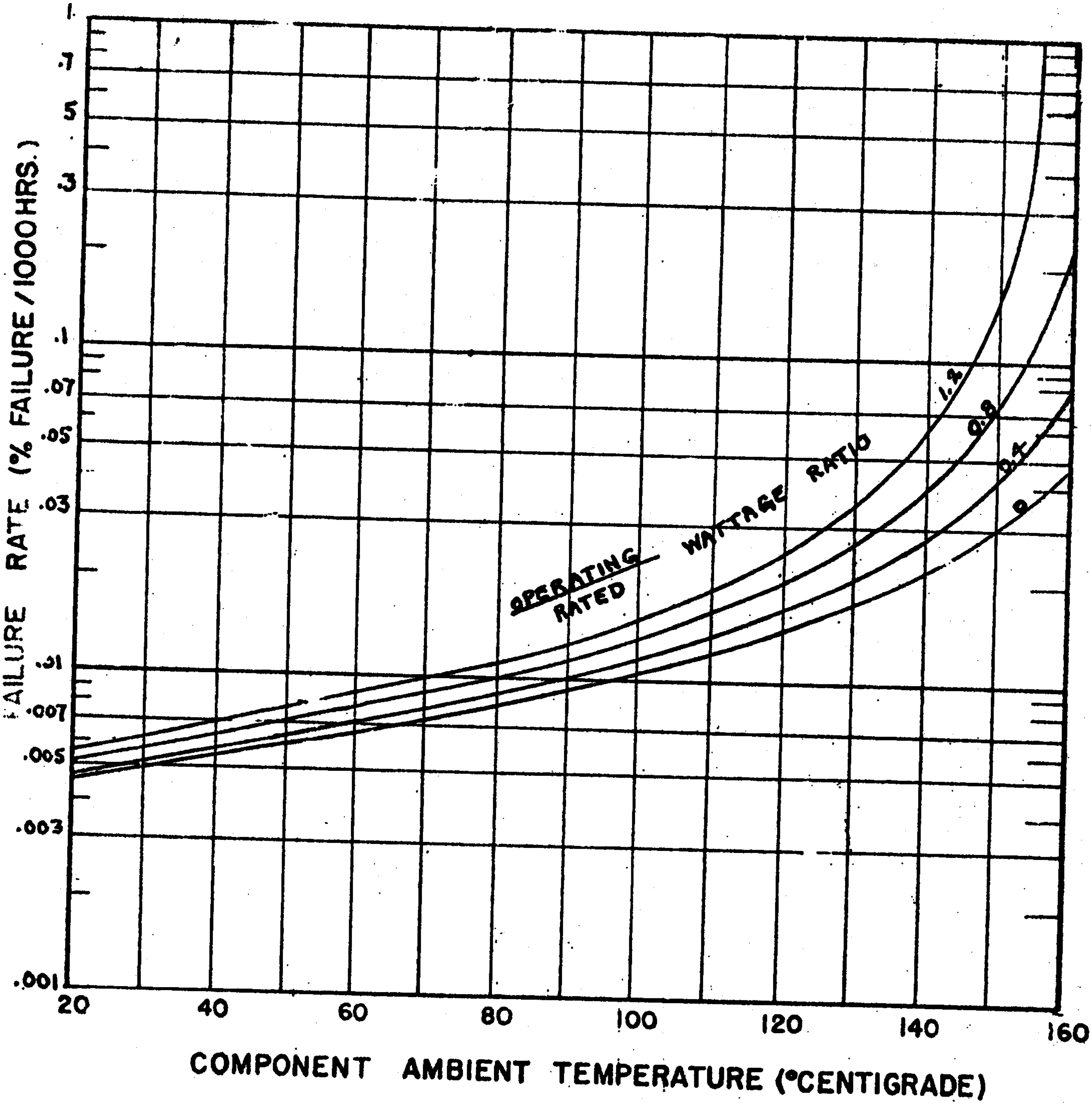

Figure 8-18

PREDICTED FAILURE RATES FOR ACCURATE WIREWOUND RESISTORS

ARS GROWTH STAGE II

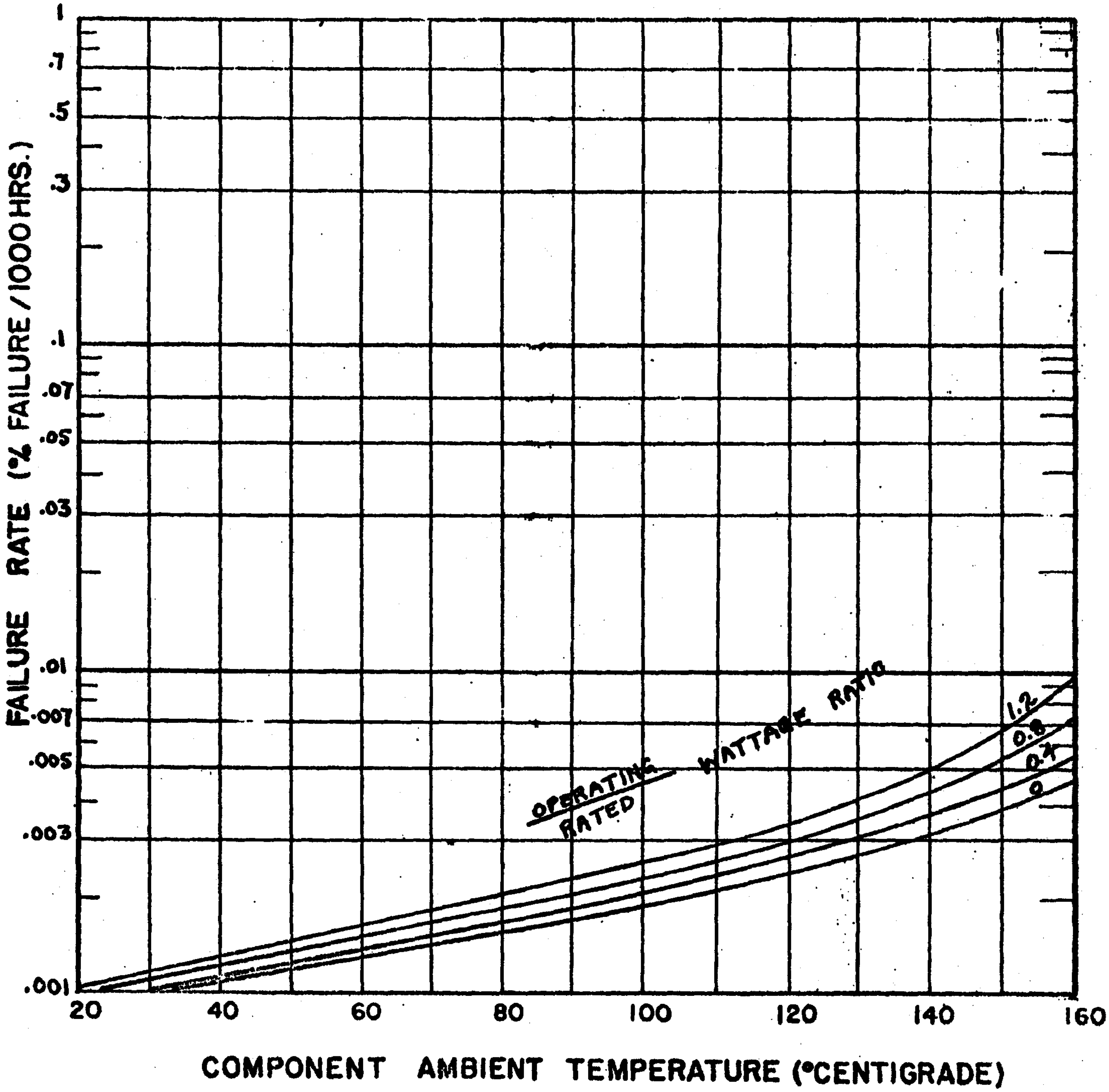

Figure 8-19

PREDICTED FAILURE RATES FOR ACCURATE WIREWOUND RESISTORS

ARS GROWTH STAGE III

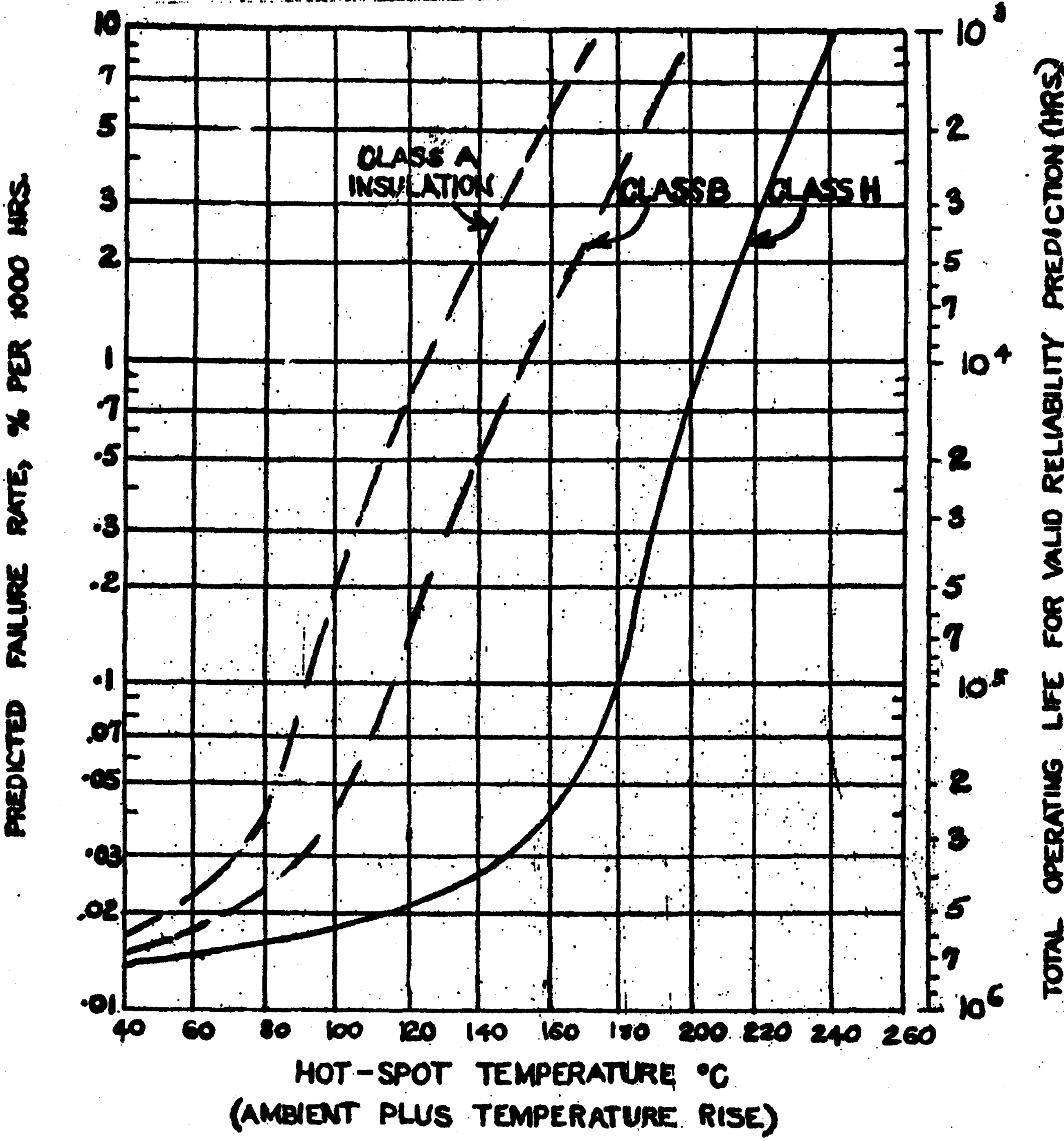

Figure 8-20

PREDICTED FAILURE RATES FOR TRANSFORMERS AND COILS

CONFIDENTIAL

ARS GROWTH STAGE I

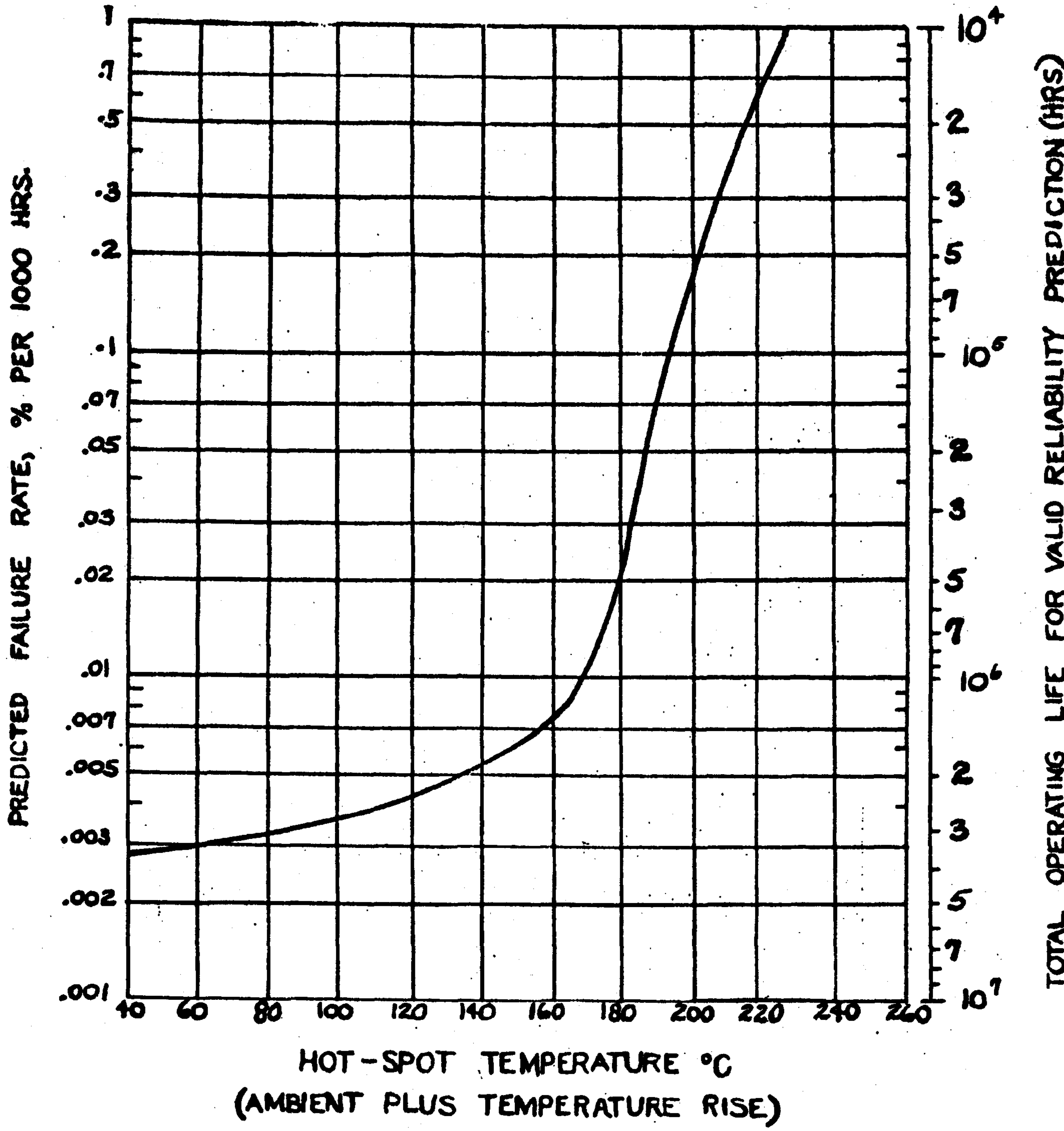

Figure 8-21

PREDICTED FAILURE RATES FOR TRANSFORMERS AND COILS

ARS GROWTH STAGE II

[redacted]

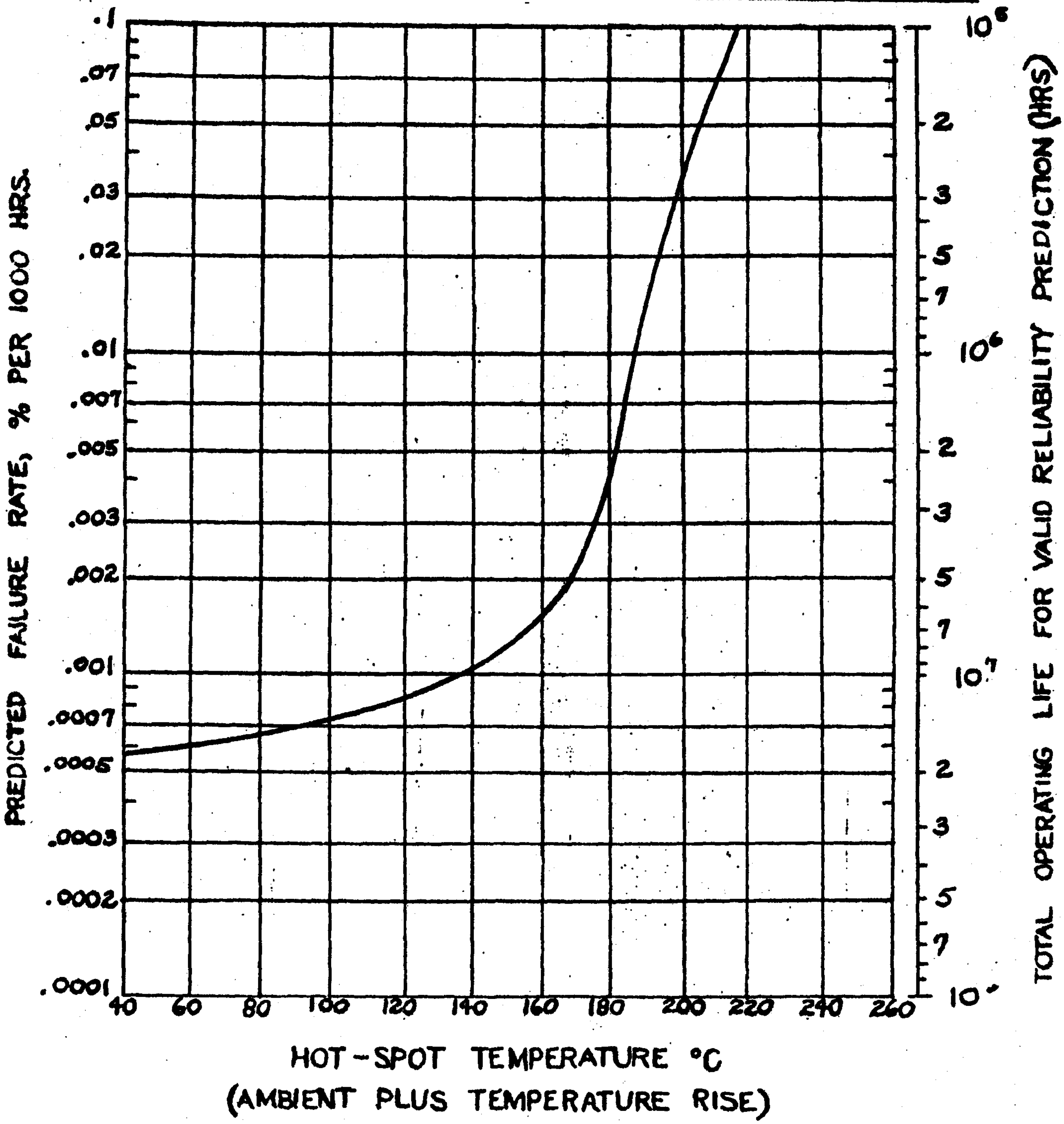

Figure 8-22

PREDICTED FAILURE RATES FOR TRANSFORMERS AND COILS

ARS GROWTH STAGE III

CONFIDENTIAL

[redacted]

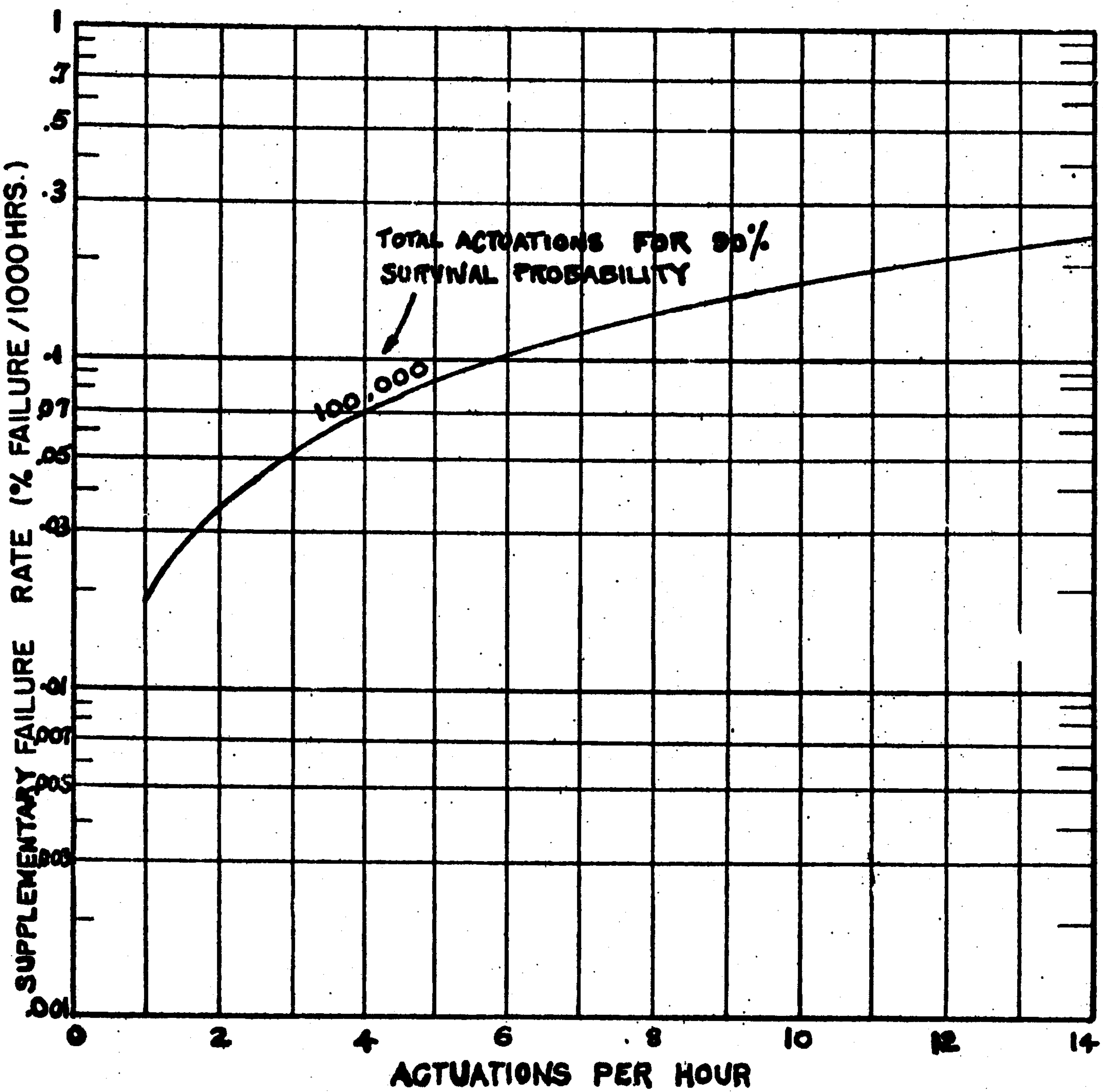

Figure 8-23

PREDICTED FAILURE RATES FOR SWITCHES AND RELAYS (PER CONTACT SET)

ARS GROWTH STAGE I

CONFIDENTIAL

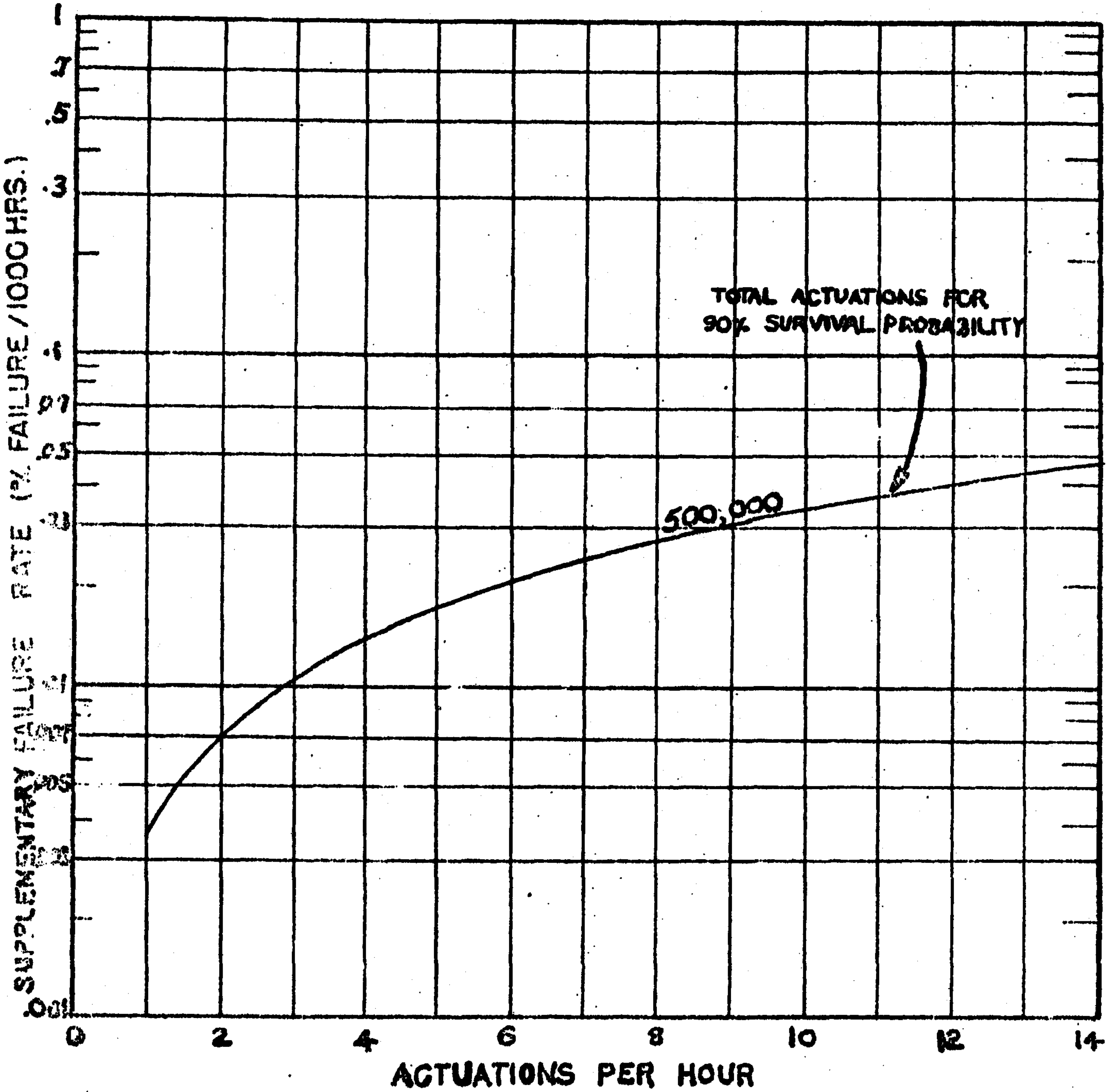

Figure 8-24

PREDICTED FAILURE RATES FOR SWITCHES AND RELAYS (PER CONTACT SET)

ARS GROWTH STAGE II

[redacted]

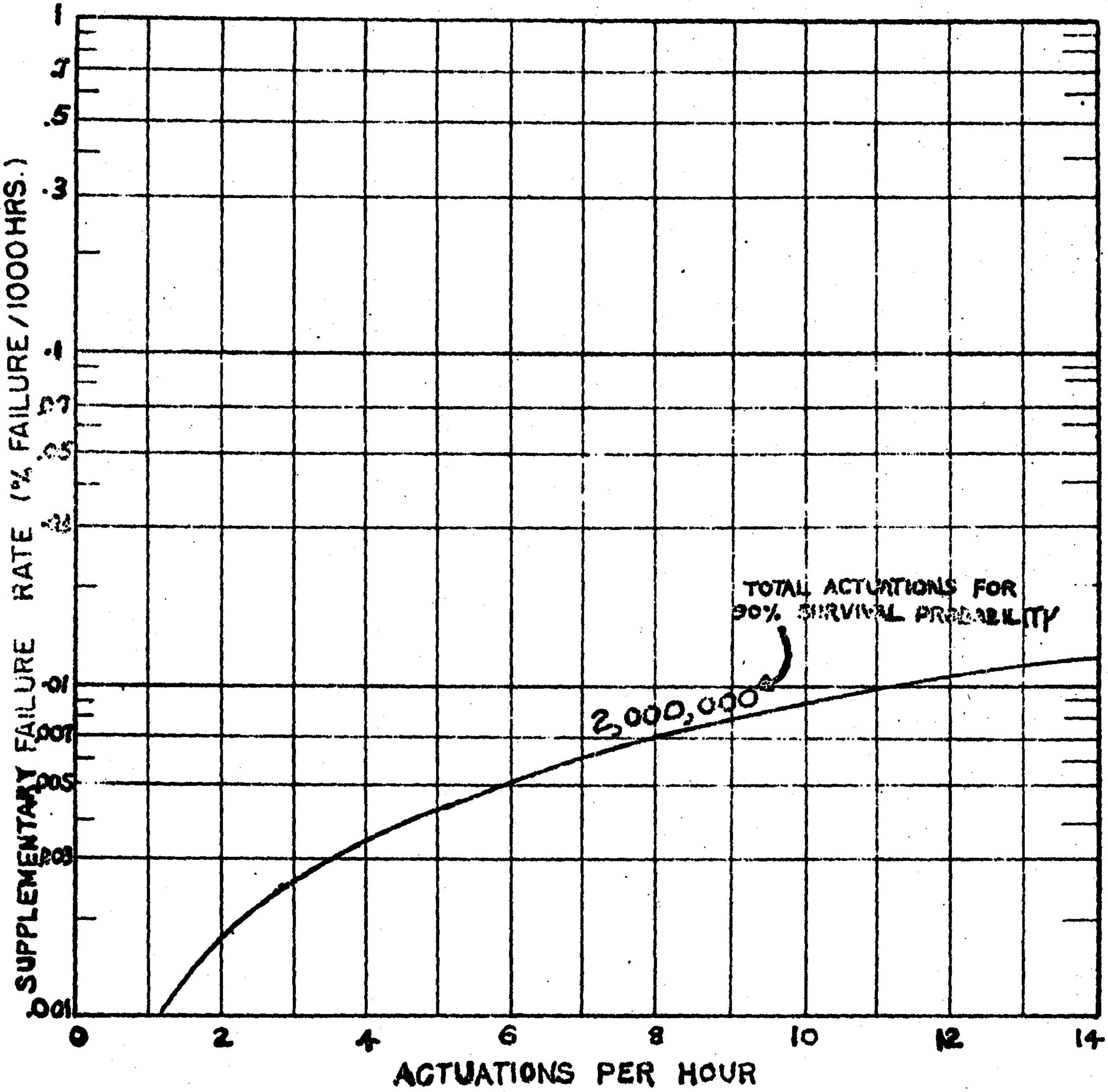

Figure 8-25

PREDICTED FAILURE RATES FOR SWITCHES AND RELAYS (PER CONTACT SET)

ARS GROWTH STAGE III

CONFIDENTIAL

[redacted]

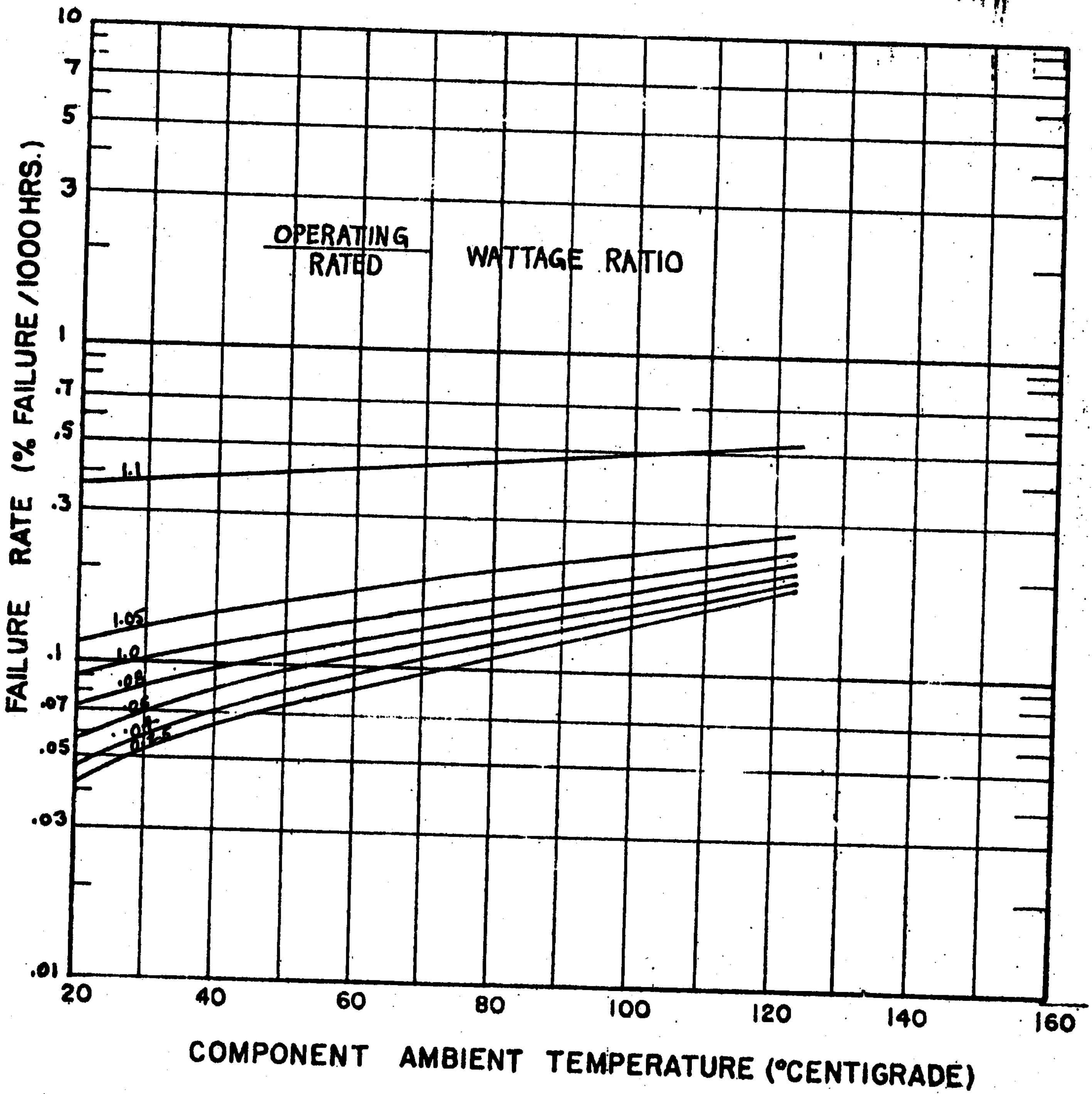

Figure 8-26

PREDICTED FAILURE RATES FOR SILICON DIODES

ARS GROWTH STAGE I CONFIDENTIAL

[redacted]

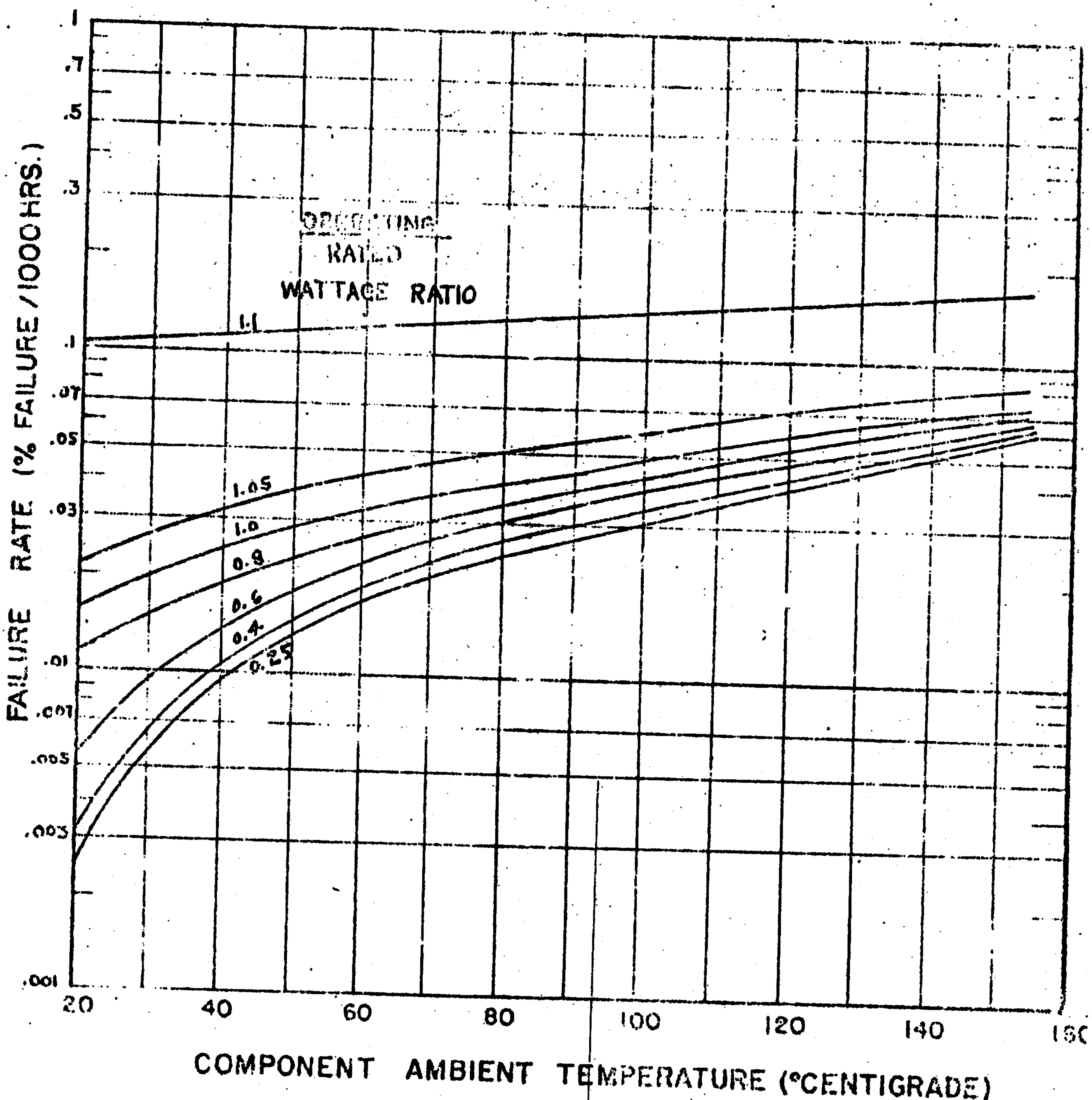

Figure 8-27

PREDICTED FAILURE RATES FOR SILICON DIODES

ARS GROWTH STAGE II

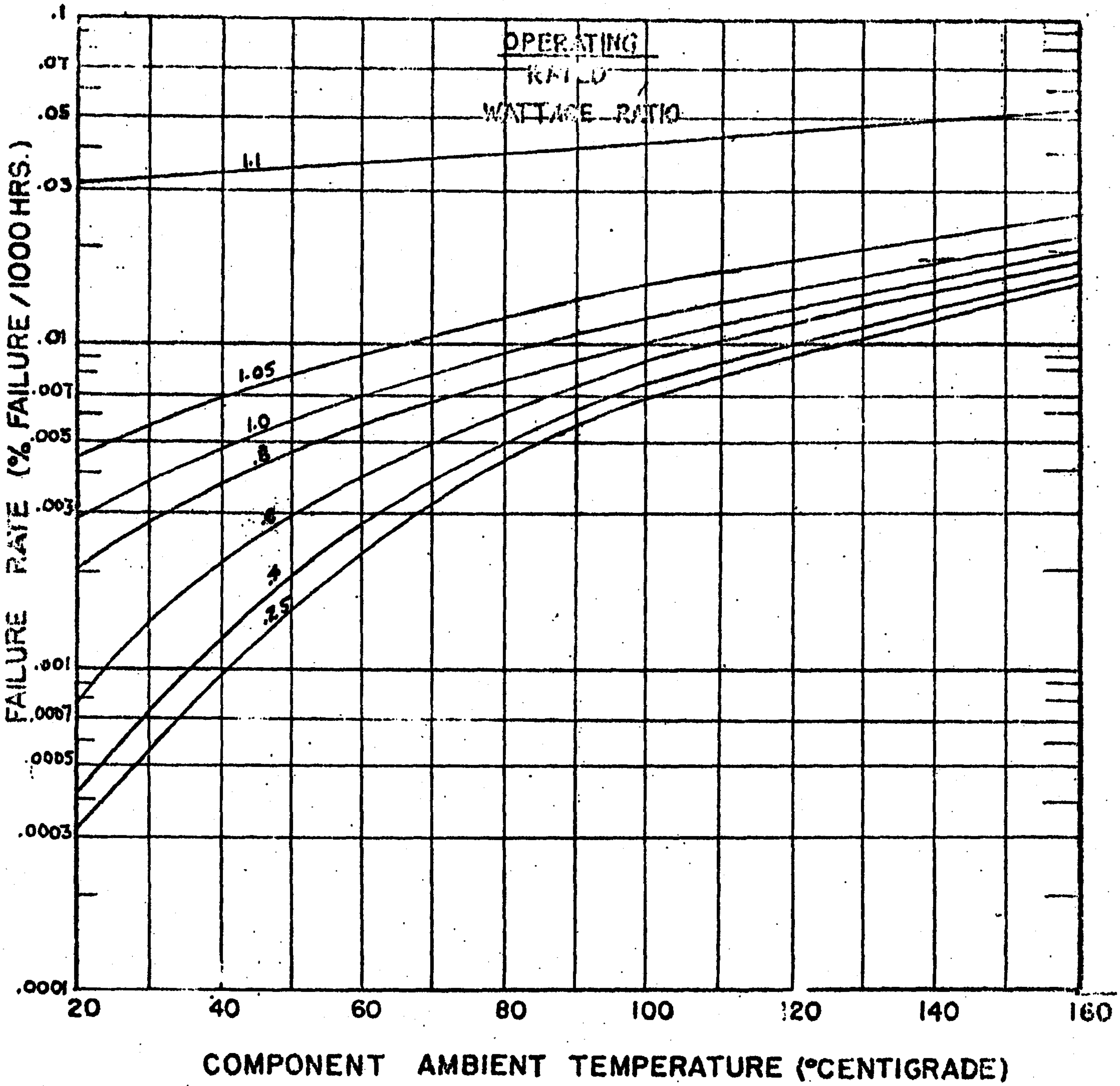

Figure 8-28

PREDICTED FAILURE RATES FOR SILICON DIODES

ARS GROWTH STAGE III

A third (and vital) issue is the matter of component part application techniques. For example, thermal convection becomes insignificant under extreme vacuum conditions, making it necessary to reevaluate the ratings of thermally dissipative components. (About one quarter of the heat sink of small composition resistors is provided by convection loss; their effective rated wattage is significantly reduced under vacuum conditions.) In deriving and applying the failure-rate curves given here, every effort has been made to provide a maximum degree of conformance with the unique factors pertinent to the ARS growth stages used as a framework for this analysis.

The failure-rate predictions made for various component factor families stress the importance of temperature as a crucial environment. However, the bulk of experience on components, materials, and even electronic equipments is based upon <u>sustained</u> temperature effects. When there is a definite temperature-time profile to be considered, some question arises as to the effective sustained temperature and the deleterious potential of the peak temperature. If an assembly of component parts were subjected to the schedule of temperature environments shown in Figure 8-29, there will be some sustained temperature (T_o) at which the <u>equivalent</u> total failure rate can be anticipated. Thus, with a given array of component parts, a function can be derived showing the dependence of the summation of part failure rates upon the equivalent ambient temperature. At an ambient temperature of 40°C this relation for many electronic assemblies indicates that failure rate increases as the fifth power of absolute temperature in this region. If the predicted failure rates for time intervals t_1, t_2, t_3 and t_4 are λ_1, λ_2, λ_3, and λ_4 respectively, there will be an equivalent failure rate λ_y such that

$$\lambda_y t_y = \lambda_1 t_1 + \lambda_2 t_2 + \lambda_3 t_3 + \lambda_4 t_4$$

and

$$\lambda_y = \sum_{i=1}^{i=4} \lambda_i \left(\frac{t_i}{t_y} \right)$$

where t_y is the total period of operation and λ_y is a time-weighted mean failure rate. Now the equivalent sustained temperature (T_y) is defined to give rise to the same effective failure rate. Noting that

$$\lambda_1 = \lambda_y \left(\frac{T_1}{T_y}\right)^5$$

and

$$\lambda_2 = \lambda_y \left(\frac{T_2}{T_y}\right)^5 \quad \text{etc.}$$

it is seen that

$$T_y = \left[T_1^5\left(\frac{t_1}{t_y}\right) + T_2^5\left(\frac{t_2}{t_y}\right) + T_3^5\left(\frac{t_3}{t_y}\right) + T_4^5\left(\frac{t_4}{t_y}\right) \right]^{1/5}$$

This provides an equivalent sustained temperature over the time region (t_y) which is equal to T_y as a time-linear, temperature-exponential weighted mean.

For application to ARS it is essential to explore the significance of this condition since it is envisioned that a launch transient will introduce a temperature peak at the early stages of the vehicle life. If the vehicle total life will be no less than about 500 hours and the period of thermal transient is to be sustained for something considerably less than one minute, a time weight factor of $\left(\frac{t_1}{t_y}\right)$ will be 3×10^{-5}. For a significant correction term arising from the effect of the temperature profile the temperature ratio factor would of necessity be very high. The estimated maximum value of $\left(\frac{t_1}{t_y}\right)$ is (530K/273K) so that

$$\left(\frac{T_1}{T_y}\right)^5 \left(\frac{t_1}{t_y}\right) = 28 \times 3 \times 10^{-5}$$

$$= 84 \times 10^{-5} = 0.084\% \text{ correction}$$

The above considerations show that the "rms" thermal hazard is relatively insignificant. However, it must be emphasized that "peak" temperature conditions can cause damage just as peak voltages may entail little total energy and yet cause failure. Peak temperature must therefore be kept below the critical level. In the ARS it is believed that this can be accomplished by the simple expedient of providing a normal amount of thermal mass to the system which will hold the thermal peak stress well within acceptable tolerances.

On the basis of what has been described above, it is essential to realize that the consideration of environmental conditions for component parts can have two vital and distinct aspects. For the purpose of material or part testing the employment of extreme-values stresses is common practice and basically justifiable. Under such evaluation the superposition of extreme-value stresses often results in test conditions far from reality. On the other hand, reliability appraisal necessitates the derivation of a "most probable" environment entailing a practical degree of superposition. Thus, in this ARS reliability analysis, component testing environments are weighed in the establishment of failure-rate predictions for complete families of component parts. The stresses applied in the reliability prediction process are not necessarily tied to these conditions, but are adjusted to reflect the most probable stress imposed by the ARS environments and packaging. These stresses are, for the most part, of a more conservative level than test conditions, since the system packaging provides a useful protective influence, particularly through transitory conditions.

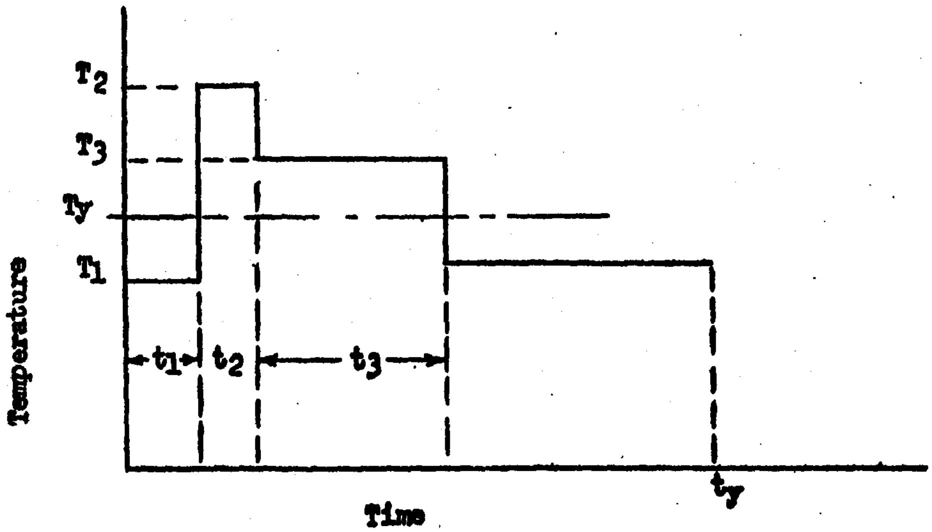

FIGURE 29

A SIMPLIFIED TEMPERATURE-TIME PROFILE

2. Most Probable Environments for the ARS Electronic Assemblies

During its service life the ARS electronic assemblies will be exposed to three distinctly different environmental complexes. The first is the ground environment, during which it is anticipated that considerable operating time will be put on the system in prelaunch adjustment and checkout. The second complex will be encountered during the launch and ascent to orbit: it is inherently transient but the most severe of the three with respect to shock, vibration and temperature. The third and residual complex is the orbital environment in the reconnaissance mode.

Only the ground environment is reliably known; the launch-ascent and orbital environments are based on estimates of upper atmosphere conditions. The uncertainty of these latter phases should be largely resolved by feedback from Project Vanguard and ARS early vehicle tests. At present, however, these environmental predictions should be recognized as having implicitly broad tolerances. In addition to the uncertainty of the environment, the present lack of a crystallized structural configuration for the vehicles introduces a further source of encertainty with respect to the ultimate effect of the environment on internal electronic equipment. Similarly, at the present stage of development, many circuit details are unresolved, as is the physical configuration and packaging. This introduces additional latitude into the estimate of local circuit environment on which a reliability prediction is based.

Within the framework of the above limitations it has nevertheless been necessary to formulate an engineering estimate of the effects of probable environment on reliability, based on the best information currently available. A summary of this information, based largely on extracts from earlier reports is contained in Table 8-3. In the sections following, the probable environments in each phase will be discussed, and comments made on mechanical design techniques applicable to their control.

<u>a. Prelaunch Phase.</u> The prelaunch phase includes the handling environments encountered in transit, assembly and/or erection, as well as those encountered in circuit operation incident to adjustment and checkout. It is observed in ammunition type vehicles that this ground environment is often as, or more, severe than that observed in flight as regards, for instance, temperature, humidity, fungus, sand, salt spray and shock.

TABLE 8-3

ARS ENVIRONMENTAL SUMMARY
PERTINENT TO ELECTRONIC ASSEMBLIES

Condition	Prelaunch	Launch and Ascent	Orbit
Missile Skin Temp.	50°C	230°C to 595°C	After nine rev. 27°C mean
Electronic Equip. Temp. (Package Skin)	50°C Parts at 65°C with 15°C rise (no ground cooling)	95°C mean parts at 110°C with 15°C rise	After nine rev. 22 - 37°C parts at 37 - 52°C with 15°C rise
Relative Humidity	Up to 100% RH if not controlled, but controllable to negligibility	---	negligible
Shock or Thrust	Possible 20g in handling if not controlled	7 - 10g	negligible
Vibration	Railroad or truck 1.5g enroute mean 2.5g peak at 60cps 3.0g peak at 400cps	Half excursion of 1" at 10 cps (approx. 11g)	negligible
Other	Dust, salt atmosphere, fungus etc. controllable in Manufacture and handling in prelaunch stage	---	Cosmic ray, Surface erosion, Vacuum ambient, Meteoric Impact, etc.

With the ARS vehicle at the Patrick Air Force Base launching site, the emperature, humidity, fungus, salt spray, sand and dust infiltration conditions will be trying. However, at the present state of the art these risk factors can be reduced to reliable levels even for unsealed or unpressurized components. This is particularly true on a project of this importance where the provision of what might be termed "prophylactic" ground facilities is justified. These would include air conditioned test spaces and provision for a continuous dry air purge of all electronic compartments while the vehicle is on the launching pad.

Shock and vibration incurred in transit and handling can be adequately attenuated by conventional missile packaging techniques,[1] especially since the logistics here are more favorable than those encountered in a field tactical situation. Similarly, ground handling conditions, equipment and personnel should be superior. Accordingly, the anticipated prelaunch phase environment can be summarized as severe in its unattenuated form but entirely practical, making use of conventional missile design techniques, together with special ground facilities.

<u>b. Launch and Ascent</u>. The principal environmental factors during launch and ascent are thrust and vibration due to propulsive and aerodynamic forces, and kinetic heating. Thrust of 7 to 10g and vibration of 10 cps, 1-inch amplitude (approximately 10g) are estimated in RCA Memo, Camden Master Control MR-1860-A. This same reference cites a maximum skin temperature in the payload zone of 530°K, approximately 300 seconds after firing. This corresponds to an equipment package surface temperature of approximately 370°K.

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1. "Fundamentals of Guided Missile Packaging", Naval Research Laboratory, July 1955.

The acceleration due to the thrust and vibration conditions is not extreme and is apparently less severe than has been encountered in several missiles including Viking (third stage), Bomarc, Navaho, Corporal and Sergeant. In general, missiles display a broad vibration spectrum, i.e. from 0 to 2000 cps. Conventional resilient isolation of ARS equipment is apparently impractical in view of the strong 10-cps component. Hard mounting, which has proven satisfactory in large missiles subject to environments even more severe than is projected for the ARS launch and ascent phase, appears the satisfactory solution.

The maximum equipment <u>package</u> surface temperature of 370°K (97°C) cited above is estimated on the basis of an average flux (watts per square inch of package area) in the absence of more refined packaging data.

Over-average dissipation is likely to run significantly higher in the final packages. Since even 97°C is in a critical temperature region for most components, the thermal problem must be clearly followed on a continuing basis as detail circuits and their packages evolve. Inasmuch as the kinetic heating is sharply transitory, some relief can be expected by utilizing the thermal lag inherent in the massive, metallic "buried-component" chassis which are characteristic of missile hard-mounting. The possibility of introducing additional thermal lag by means of insulation between the missile skin and electronic packaging is interesting. To the degree that it is practical, the use of low emissivity package surfaces and internal skin surfaces will reduce the radiant heat input from the vehicle skin during ascent. Similar insulating effect is inherent in the potting compounds used to embed circuits for hard mounting. Design techniques which introduce low thermal diffusivity (K/ C) are of obvious utility in resisting the thermal transients anticipated in ascent, providing of course that the overall conductivity is not reduced to a point where steady-stage (orbital) heat transfer is inadequate.

As the package design requirements crystallize time-temperature simulation tests will indicate whether the above "natural" methods are adequate or whether refrigeration must be furnished. Such refrigeration, if required, might be provided by an internally contained and expendable evaporative refrigerant or by supercooling the massive chassis immediately prior to launch. The latter could be accomplished by coring all high dissipation chassis and passing ground supplied refrigerated air through the cores, thereby lowering the chassis temperature significantly prior to firing. The ground supplied air would of course be cut off at the time of firing. This technique would favor the use of dry air pressurization to forestall condensation in circuit packaging.

In summary, the launch and ascent environment will be severe, though of short duration. The thrust, shock and vibration requirements currently anticipated can be met with present missile packaging techniques. The thermal problem, based on predicted maximum case temperatures of 97°C, is also severe, but is believed capable of attenuation with conventional packaging techniques employing "natural" heat transfer. Should subsequent circuit developments lead to higher dissipation densities, resort to refrigeration may be required for the ascent. In any event, it is practical to simulate this thermal environment as the circuitry and packaging evolve, and tests should be employed to monitor its severity and to indicate whether or not further techniques are required. In other words, while the attainment of a reliable thermal environment for the circuitry may require considerable design and evaluation effort, there is no apparent reason why the final design cannot be adequate.

c. Orbit. The environment to be encountered in the orbital phase is most important in that it comprises the one in which the vehicle settles down into and spends its useful (reconnaissance) life.

Mildness characterizes the predicted thermal environment. Vehicle skin temperatures (0.031-inch stainless skin) will vary between about 240° and 320°K (-33° to plus 47°C) depending on the solar exposure, but so far as the payload is concerned, this variation is damped out to between 308° and 314°K, with a mean of about 310°K (37°C). This estimate is based on a dissipation density of 5.3 watts per cubic foot. For zero dissipation density, a mean package skin temperature of about 295°K or (22°C) is predicted. These temperature ranges are clearly conducive to reliability and are no more or less severe than those encountered in present airborne systems.

Once the vehicle has settled into orbit, the almost complete absence of external forces on the vehicle makes the thrust-shock-vibration environment minimal. The use of internally applied attitude correction or the operation of electromechanical devices must, of course, be controlled so that these disturbances do not jeopardize reconnaissance resolution. But these disturbances could not conceivably pose a mechanical threat to the equipment or circuitry. That is, equipment which can survive the thrust-shock-vibration environments in prelaunch and launch should thrive on that of the orbit.

The uncertain portions of the orbital environment are those associated with the ionosphere. These are the degree of risk imposed by cosmic ray and high ultraviolet radiation, meteoric impact and damage, and skin erosion resulting both from the high speed bombardment of atomic oxygen and molecular nitrogen. These factors are felt to be non-critical but they require feedback from high-altitude research vehicles (such as Vanguard) before the [redacted] ted. The effect of high vacuum (10^{-8} to 10^{-10} mm Hg) on those circuit parts which are unpressurized may present some problems in material degradation due to degassing and loss of volatile solvents. The presence of highly ionized, relatively dense residual gases within the vehicle may also present a risk to unpressurized unsealed electronic equipment. The solution to these latter uncertainties perhaps lies in encapsulation techniques.

Comments on the orbital environment can be summarized by observing that the known or predictable factors are mild or minimal, while those which are uncertain await feedback from early vehicle tests before the applicable design criteria can be outlined.

d. Conclusion. Except for the orbital phase, present missiles are operating in environments as, or more severe, than those projected for ARS. Accordingly, there is no apparent reason why the judicious extrapolation of the present state of design art should not be an adequate initial guide in the growth of a highly-reliable ARS system. With regard to the uncertainties of the orbital phase, there are areas in which test vehicle feedback is required to firm up design criteria, but it is felt that these uncertain factors will be of a limiting, rather than prohibitive degree.

3. Representative Satellite Configurations[1]

Detailed information on many of the factors which will influence the reliability and life of an earth satellite is as yet not available. Highly reliable performance of such a vehicle on a military assignment must therefore be obtained through a growth program of successive satellite flights. Each

1. For the purpose of this study a representative electronic system is one which will have the same level of complexity as the final design will probably entail. There is no claim to uniqueness in the formulation of a representative system and the functional demands visualized are used solely to establish a criterion for reliability approach.

vehicle will contain more complex equipment and provide more detailed information on high altitude conditions as they relate to reliability. However, sufficient data are already available to permit gross evaluation of the reliability of the first satellite to be launched. Furthermore, future extensions in the state of the art and future plans for more complicated satellites are now well enough defined to permit an extension of the reliability analysis to two stages of growth beyond the present state as shown in Figure 8-30.

The objectives of this reliability study make it mandatory that a series of assertions be made with regard to the ARS enviromments, systems and circuits to set the stage for the consideration of the concrete facts and figures of reliability prediction. Such tentative decisions are necessary to avoid the picture for the sole purpose of reliability computation.

a. Configuration and Reliability of Growth Stage I. It can be assumed that the first satellite flight will be devoted solely to research to the exclusion of military reconnaissance. Such a vehicle would contain various scientific instruments with associated telemetering equipment to relay the information to earth. It would contain command equipment to activate the scientific equipment, a beacon to aid in determining the position of the satellite and a stabilizing system to aid in keeping the satellite directed toward earth. A slow scan vidicon camera chain should be included as part of the instrumentation to provide information to aid in the design of visual reconnaissance satellites. Such a system is shown in the block diagram Figure 8-31.

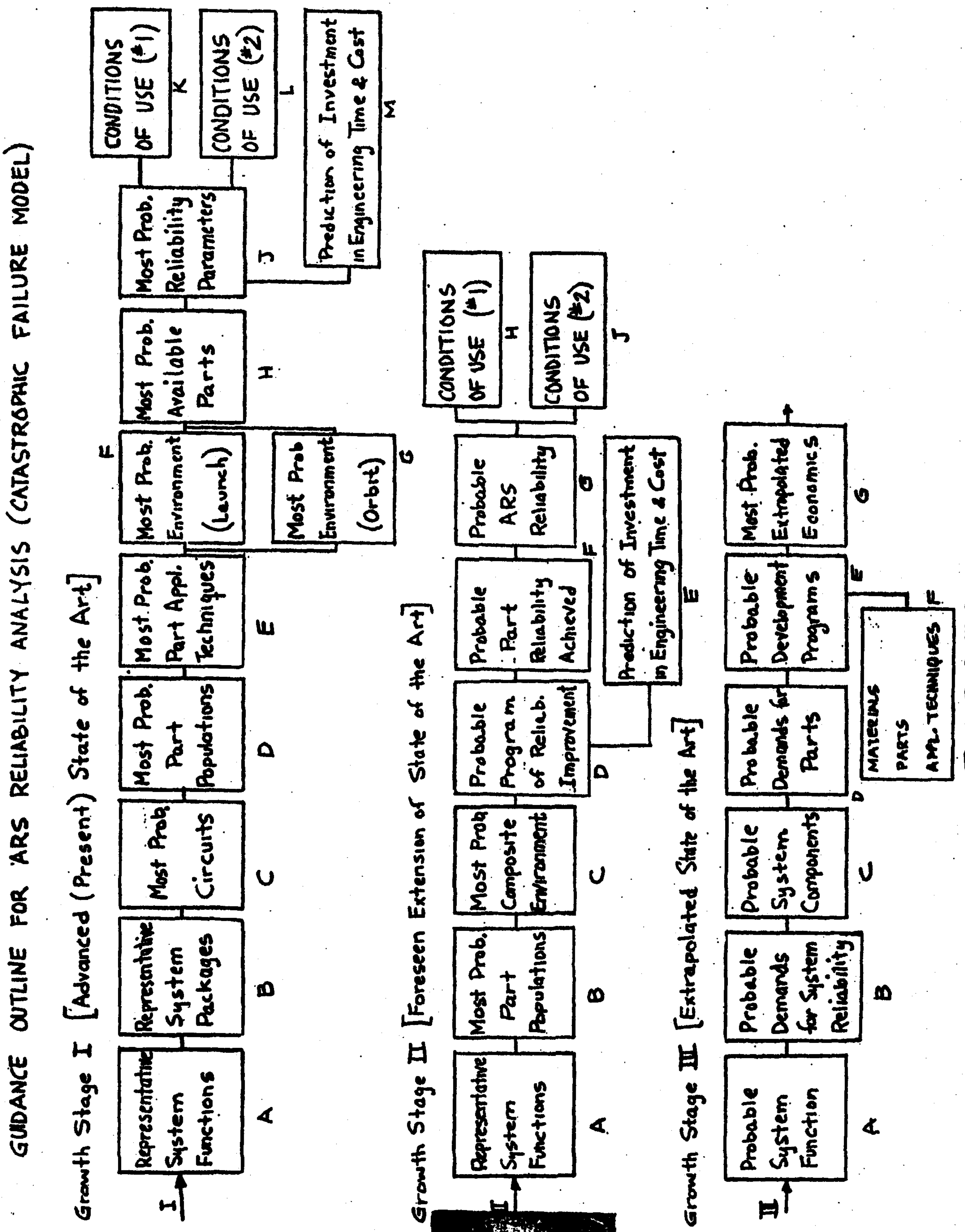
GUIDANCE OUTLINE FOR ARS RELIABILITY ANALYSIS (CATASTROPHIC FAILURE MODEL)
Growth Stage I [Advanced (Present) State of the Art]
I
Representative System Functions
A
Representative System Packages
B
Most Prob. Circuits
C
Most Prob. Part Populations
D
Most Prob. Part Appl. Techniques
E
Most Prob. Environment (Launch)
F
Most Prob Environment (Orbit)
G
Most Prob. Available Parts
H
Most Prob. Reliability Parameters
J
CONDITIONS OF USE (#1)
K
CONDITIONS OF USE (#2)
L
Prediction of Investment in Engineering Time & Cost
M
Growth Stage II [Foreseen Extension of State of the Art]
II
Representative System Functions
A
Most Prob. Part Populations
B
Most Prob Composite Environment
C
Probable Program of Reliab. Improvement
D
Probable Part Reliability Achieved
E
Prediction of Investment in Engineering Time & Cost
E
Probable ARS Reliability
F
G
CONDITIONS OF USE (#1)
H
CONDITIONS OF USE (#2)
J
Growth Stage III [Extrapolated State of the Art]
III
Probable System Function
A
Probable Demands for System Reliability
B
Probable System Components
C
Probable Demands for Parts
D
Probable Development Programs
E
MATERIALS
PARTS
APPL. TECHNIQUES
F
Most Prob. Extrapolated Economics
G

FIGURE 30

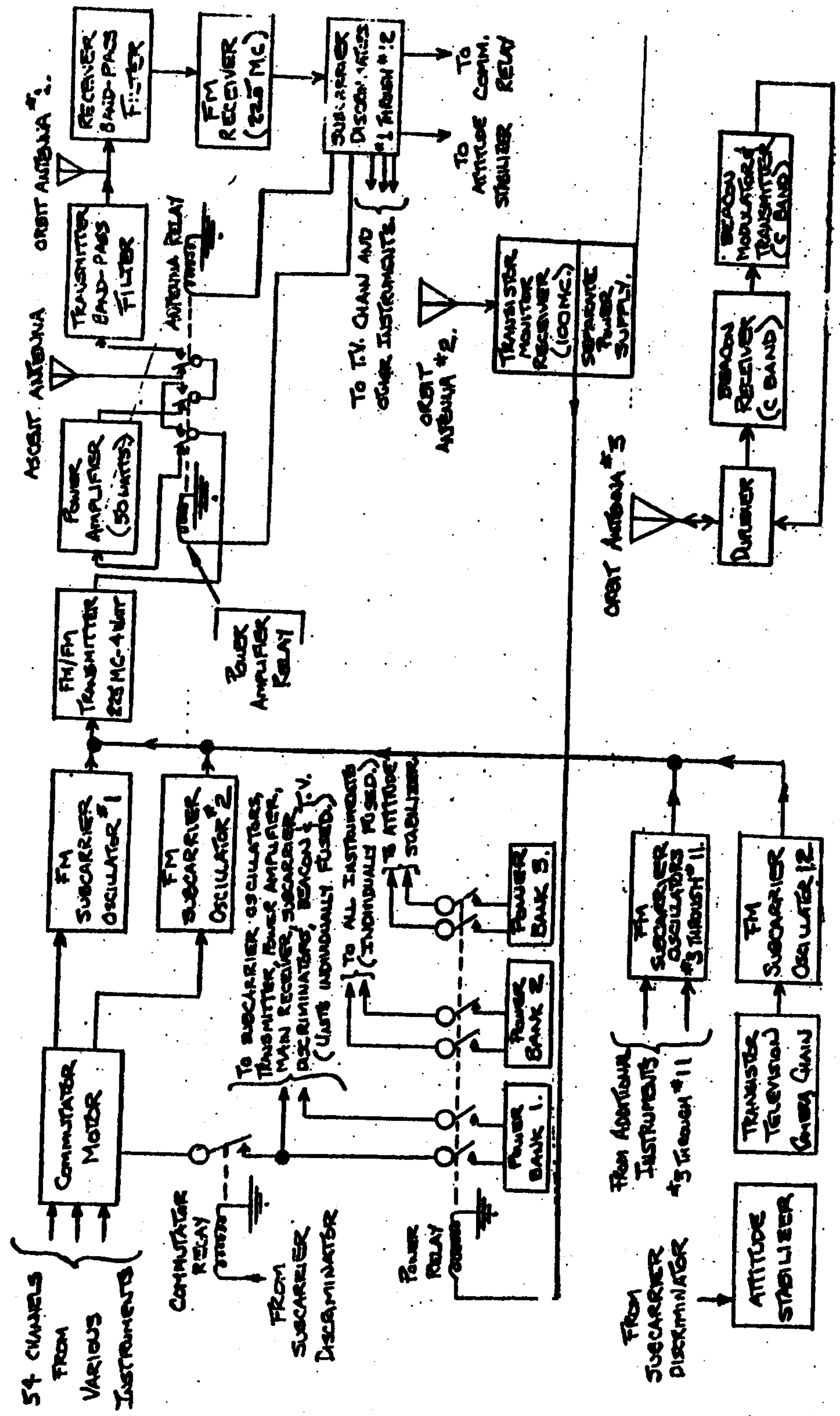

FIGURE 31
BLOCK DIAGRAM OF REPRESENTATIVE ARS ELECTRONIC EQUIPMENT.
(ARS GROWTH STAGE I.)

It is important to note that the system proposed in the block diagram of Figure 8-31 is representative of the type of equipment which would be included in a research satellite at the first stage of growth. This is true for the complexity of the equipment as well as for the functions it performs. Even though the system in its final form may be different than the system presented here, its reliability will depend upon the same environmental conditions, upon the same component materials, and upon approximately the same component populations. Therefore, the numerical reliability figure arrived at for this representative system should hold for the final system built into the first satellite.

In the research vehicle, as in the other vehicles to follow, most of the electronic equipment will be in operation during the launching phase. In the orbit phase, however, only the monitor receiver and possibly the attitude stabilizer will have a duty factor of one. Although it is anticipated that the more advanced reconnaissance satellites will be interrogated by two ground observation stations located with the continental United States, the research vehicle needs only one such interrogation station. This would limit the interrogation time per orbit to approximately 7 minutes since reliable tracking and communication is restricted to an angle of 15° or more above the horizon. When the vehicle comes into range, the monitor receiver would activate the power supplies and the transmitting and receiving equipment and would place all instrumentation equipment in "stand-by". Individual pieces of instrumentation would be required to supply information to the telemetering transmitter upon command sent to the main receiver. In general, each instrument will have a low duty factor. The transmitting and receiving functions will have a duty factor which corresponds to the duration of observation. A summary of these duty factors is shown in Figure 8-32.

Figure 8-32 indicates that the duty factor on the vertical stabilizer can vary from 0.11 to 1. This function is required to stabilize the vehicle during operation of the television camera chain only. In the research vehicle (Growth Stage I) the camera chain will probably be operated no more than is necessary to prove the feasibility of such a device. This might require only one or two orbits of flight. However, it seems advisable to evaluate the attitude stabilizer on the basis of a continuous demand, since the camera chain in the reconnaissance satellite will have high duty factors.

Figure 8-31 shows the four main functions of the ARS research vehicle. These are the beacon function, the vehicle stabilization function, the instrumentation function and the telemetering function. Failure of any one of the instruments will not affect the collection of information from the other instruments. By way of contrast, a failure in the telemetering transmitter would cause complete loss of all sources of relayed information. Between these two extremes of parallel and series type failures[1] other failures can occur which are not as clearly defined. As an example of this, an inoperative main receiver would normally be considered to make the entire satellite telemetering system inoperative. However, if the system incorporates an automatic sampler which is activated when the main receiver fails, a form of redundancy has been incorporated which will make the system more reliable and which must be reflected in the final reliability numeric. Factors outside of the vehicle also play a part in determining whether a unit failure produces a series or parallel effect. Beacon information received on the ground might be used to train ground telemetering antennas. If this is the case, loss of the beacon function would make the entire system inoperative.

1. Carhart, R.R., "A Survey of the Current Status of the Electronic Reliability Problem" - U.S. Air Force, Project Rand, Rand Corp. Research Memo #RM-1131 dated 14 Aug. 1953.

Unit	"On Time" per orbit	Duty Factor
Main Receiver	7	0.08
Subcarrier Disc	7	0.08
Transmitter	7	0.08
Power Amplifier	7	0.08
Commutator	7	0.08
Subcarrier Oscs 1 and 2	7	0.08
Subcarrier Oscs 3 to 11	2	0.02
Subcarrier Osc 12	0.7	0.008
T.V. Camera Chain	0.7	0.008
Other Instrumentation	2	0.02
Beacon Rec. and Transmitter	7	0.08
Monitor Receiver	90	1.0
Vehicle Stabilizer	10 to 90	0.11 to 1

Figure 8-32. "On Time" and Duty Factor for the Various Electronic Functions.

Because of the interplay of these factors it is necessary to establish a firm "system operation" concept before a numerical reliability prediction is attempted. For this study it will be practical to assume that all of the units of instrumentation fail in parallel. It will be necessary therefore to evaluate only one such unit, the television camera chain with its associated subcarrier oscillator - to ascertain the overall reliability of the system. All other units will be considered to fail in series. This will result in a slightly pessimistic figure (lower than actual mean life) for the system reliability.

ENGINEERING APPLICATION OF RELIABILITY MODELS

Detailed information concerning the circuits and components employed in each of the units of the representative ARS electronic system is given in the appendix to this chapter, Circuit Functions and Failure Rate Analysis. Two of the units in this system employ transistor circuits. This is based upon an anticipation of reasonable advances in the state of the art at the time of the first satellite launching. It is probable that approximately 50 percent of the system will be transistorized for Growth Stage II. Growth Stage III will probably be transistorized for the most part.

The importance of adequate safety factors in the application of components has been emphasized in previous portions of this report. Assuring such safety factors in practice is primarily a matter of policy determination before the design is begun. In the case of the ARS systems, for example, it would seem reasonable to keep the stresses on plate resistors below 0.4 of realistic rated wattage. Similar policies have been established for the other components in the ARS system and are reflected in the stress columns of the appendix.

The summary table in the appendix indicates that the representative electronic equipment presented here, operating with the temperature profile and electrical stresses indicated above, will have a mean time to catastrophic failure of 9,800 hours. It will be remembered, however, that the actual operating time of the first satellite will be limited to approximately 500 hours because of the limited battery energy available. Figure 8-33 shows the probability of survival of the satellite as a function of time, "time zero" being the time of launching A probability higher than 95 percent is anticipated for the entire period of zero to 500 hours, the time at which the power sources aboard the vehicle will fail. It should be emphasized again that the high survival probability is brought about by conservative duty factors for the various electronic functions, by conservative application of the component parts and by conservative environmental conditions.

While it is quite possible that the usefulness of the satellite might be destroyed soon after launching by some environmental condition not taken into account, such as failure by meteoric impact, the probability of such a failure is assumed to be remote and would influence the probability of survival curve to a very limited extent.

b. Growth Stage II Considerations. The vehicles of Growth Stage II will also most likely be devoted predominately to research. The research problems, however, will be different. It is anticipated that during Growth Stage I interest will be concentrated on obtaining information about high altitude environmental conditions, stabilization problems and orbital characteristics. Growth Stage II will probably be concerned with obtaining information about, and developing, visual reconnaissance techniques. While it is anticipated that the first vehicles of Growth Stage I will be launched in mid-1958, the first vehicles of Growth Stage II will probably not be launched until mid-1960. This should provide an excellent opportunity to improve component part performance and reliability for Growth Stage II by incorporating the findings of Growth Stage I into their design. This has been reflected in the Failure Rate charts for Growth Stage II, which cover in detail predicted improvements in materials, quality control and application techniques.

Since Growth Stage II vehicles will be devoted primarily to visual reconnaissance research, the electronic equipment employed in the vehicles will vary from that included in prior vehicles (used for high-altitude research) both in complexity and form. They will probably still contain beacon, telemetering, and command equipment but the monitoring equipment will probably be replaced with a program clock and much of the instrumentation

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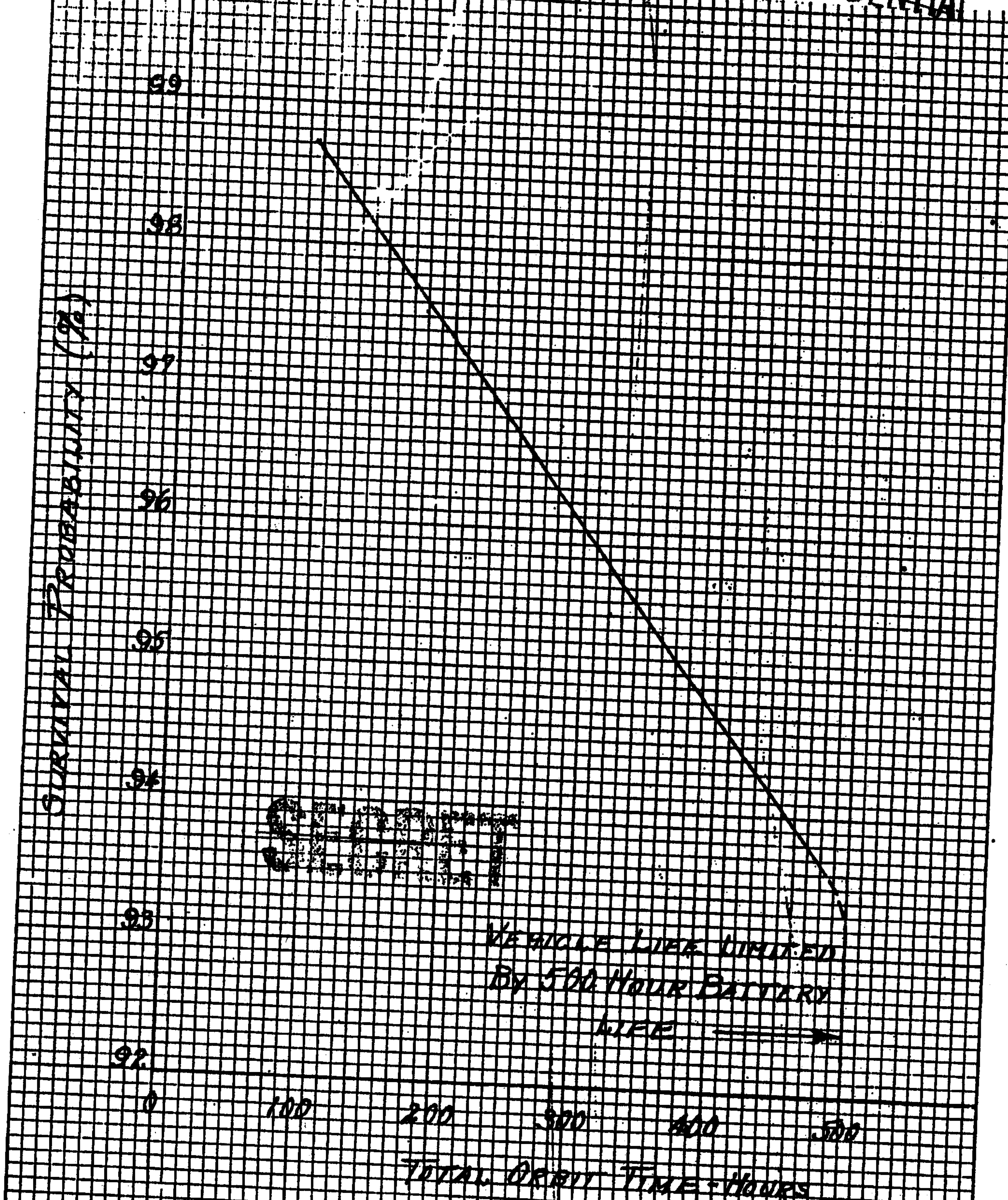

FIGURE 33
ARS GROWTH STAGE I
SURVIVAL PROBABILITY VS TOTAL ORBIT TIME

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in the earlier vehicles will be removed. A more complicated television function will replace this instrumentation. Not only will higher resolution be required, demanding a more precise optical system, an image orthicon in place of the vidicon and a wide-band transmission system, but storage of the visual information will also be required. Several methods of accomplishing such storage are being developed and have been discussed in previous portions of this report. One of the more promising of these would seem to be the electrostatic tape storage. This would require additional read-in and read-out equipment. (See Figure 8-34)

Another difference in the vehicles of Growth Stage II is that they may operate on solar energy. The vehicles will probably contain solar batteries. Even at today's state of the art, solar batteries are highly reliable although inefficient. The principal difficulty to be anticipated from this source of power is the unreliability entailed in interconnecting the vast number of cells required and providing a satisfactory mechanical structure of the large collection areas necessary. Since the vehicles are required to operate within the shadow of the earth, storage batteries, charged from the solar cells, may also have to be included.

Duty factors in the visual reconnaissance satellite will likely be higher than they were in the high-altitude-research vehicle. The television camera will probably be operating at least half of the time and the information storage equipment will probably be operating under continuous demand. Telemetering and beacon equipment will most likely be operating at approximately four times the rate of the Growth Stage I satellite. Furthermore, the reconnaissance satellites will undoubtedly incorporate a higher number of "parts peculiar". These factors would have a tendency to lower the satellite survival probability.

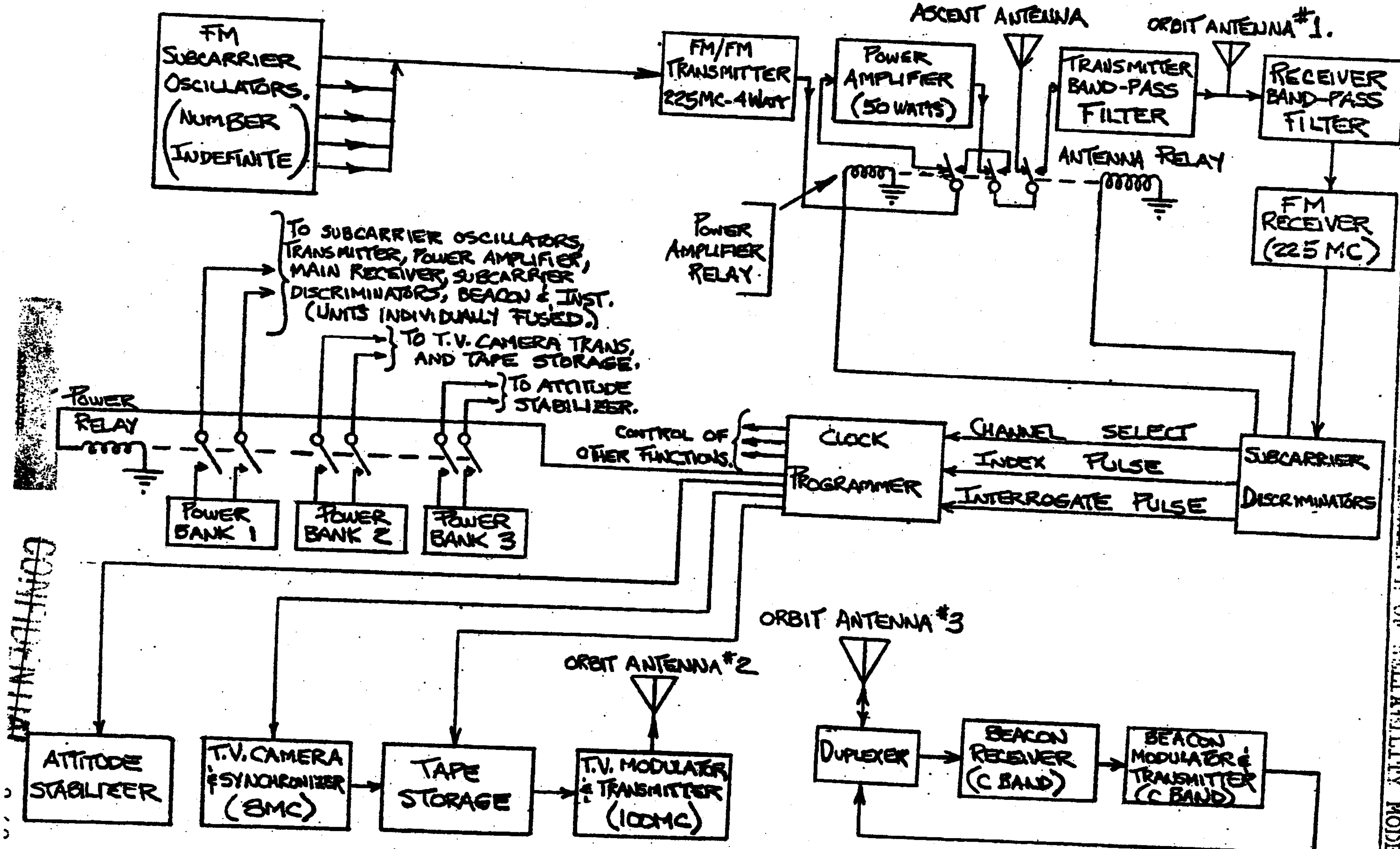

FIGURE 34

BLOCK DIAGRAM OF REPRESENTATIVE ARS ELECTRONIC EQUIPMENT. (GROWTH STAGE II)

Balanced against this, however, are the improvements made in packaging techniques and high-population components in the intervening time and the development and use of redundancy techniques. Special components with short times to wearout failure, such as magnetrons and traveling-wave tubes, could be replaced automatically with duplicate units upon approaching wearout time, since redundancy in these items does not add prohibitive weights. The effects of increased complexity versus improved technology are reflected in the Summary Table for Growth Stage II in the appendix. The probability of electronic equipment survival as a function of time for such a satellite is then given by the curve of Figure 8-35. Here again it should be emphasized that the satellite has a high probability of survival up to the time at which special components begin to wear out. (See Figure 8-34)

<u>c. Growth Stage III Considerations</u>. Operationally, Growth Stage III satellites will be divided into two main categories; those designed for visual reconnaissance, and those designed for detection of electromagnetic sources. As contrasted to Growth Stage II vehicles, these vehicles might obtain energy from nuclear power supplies. It is difficult at this time to predict what effect the nuclear supplies will have on the reliability of the vehicles. Assuming, however, that these problems can be solved by adequate packaging techniques, the environmental conditions encountered for Growth Stages I and II will predominate.

Furthermore, Growth Stage III satellites will have about the same complexity as the Growth Stage II satellites. However, approximately four years will have elapsed since the launching of the first satellite. Projected development of components and techniques would indicate that at this time a probability of survival for the Growth Stage III vehicles similar to that given in Figure 8-36 could be anticipated.

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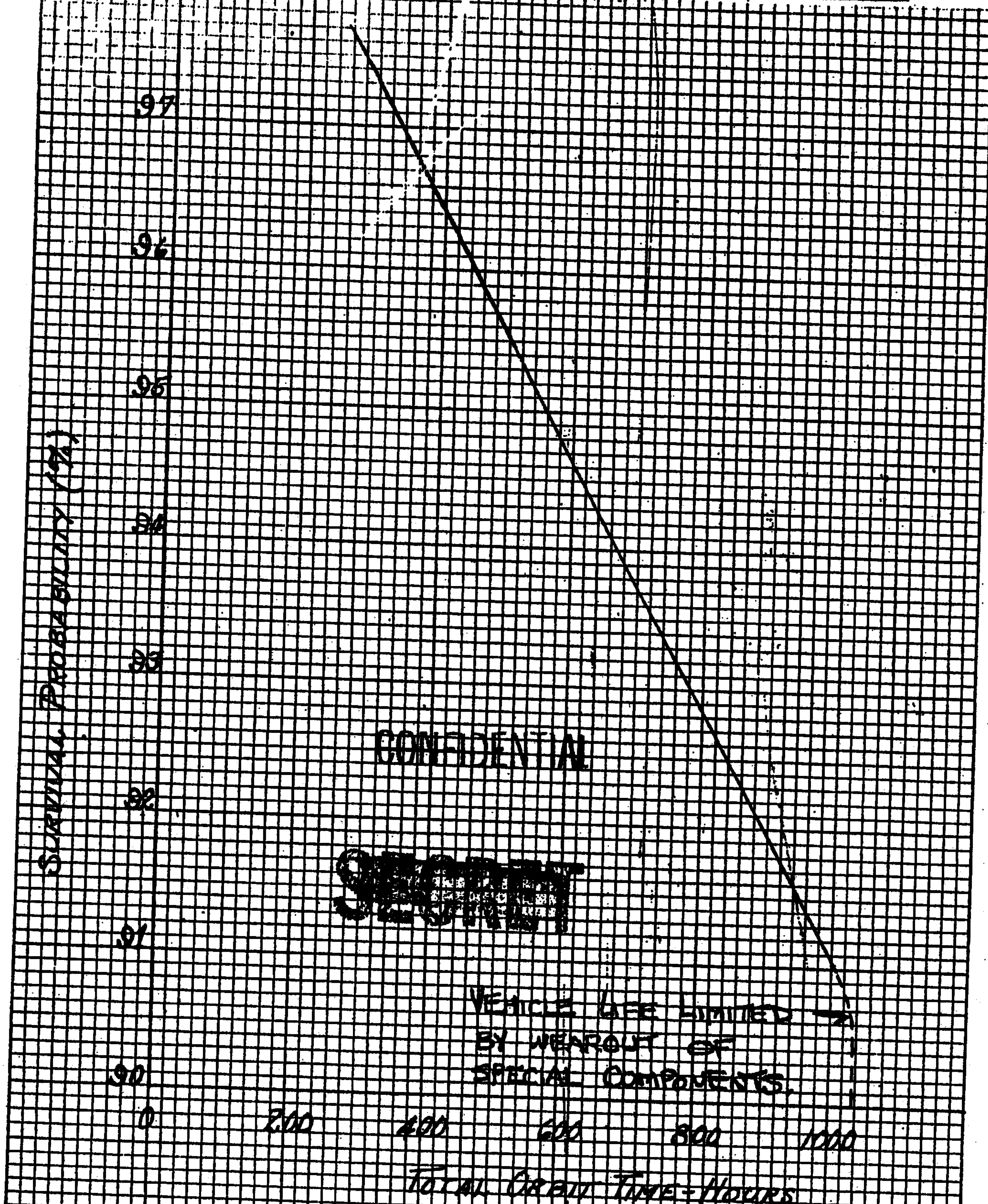

FIGURE 35
ARS GROWTH STAGE II
SURVIVAL PROBABILITY VS TOTAL ORBIT TIME

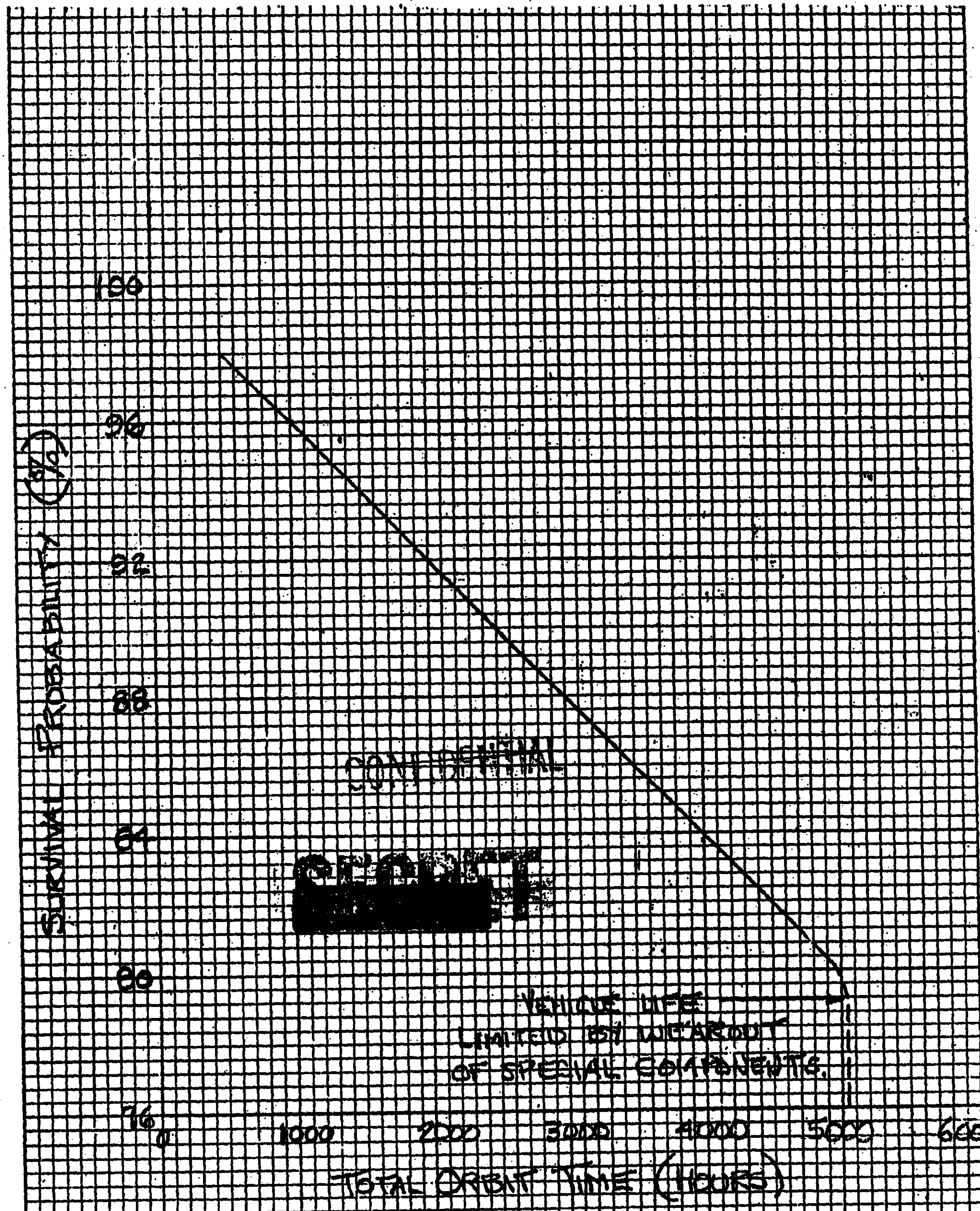

FIGURE 36

ARS GROWTH STAGE III

SURVIVAL PROBABILITY VS. TOTAL ORBIT TIME

APPENDIX TO CHAPTER VIII

CIRCUIT FUNCTIONS AND FAILURE RATE ANALYSIS

SUMMARY OF COMPONENTS AND FAILURE RATES FOR GROWTH STAGE I

Unit	Component Populations: Tubes	Transistors	Resistors	Capacitors	Misc.	Failure Rate %/1000hrs.	Duty Factor	Adjusted Failure Rate %/1000hrs	Sub-Total Failure Rate %/1000 hrs.
MONITORING FUNCTION									
Monitor Receiver		4	14	9	1	.657	1.0	.657	
Power Relay					1	.13	*	.13	.787
TELEMETERING FUNCTION									
FM/FM Transmitter	3		16	20	7	3.86	.08	.309	
RF Power Amplifier	1		6	5	4	2.25	.08	.180	
Power Amplifier-Relay					1	.09	*	.09	
Transmitter Band-Pass Filter				2	2	.031	.08	.003	
Antenna Relay					1	.0005	*	.0005	
Receiver Band-Pass Filter				2	2	.031	.08	.003	
FM Receiver	11		45	46	15	14.1	.08	1.13	
Subcarrier Discriminator	1		2	4	5	.997	.08	.080	1.796
TELEVISION FUNCTION									
Television Camera Chain	1	22	83	24	16	6.67	.008	.053	
FM Subcarrier Oscillator	2		7	10	3	1.96	.008	.016	.069
BEACON FUNCTION									
Beacon Receiver	2		8	3	2	2.79	.08	.223	
Beacon Modulator and Transmitter	12		51	19	23	28.3	.08	2.26	2.48
ATTITUDE STABILIZATION FUNCTION									
Attitude Stabilizer (3 units)	6		6		6	5.49	1.0	5.49	5.49
GRAND TOTALS	39	26	238	144	89				10.6

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ADJUSTED GRAND TOTAL FAILURE RATE (includes allowance of 25% for parts peculiar) 13.3

* Basic failure rate for relays includes duty-factor (operates per hour)

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SUMMARY OF COMPONENTS AND FAILURE RATES FOR GROWTH STAGE II

Unit	Component Populations: Tubes	Transistors	Resistors	Capacitors	Misc.	Failure Rate %/1000hrs	Duty Factor	Adjusted Failure Rate %/1000hrs	Sub-Total Failure Rate %/1000 hrs.
MONITORING FUNCTION									
Program Clock		4	14	9	1	.171	1.0	.171	
Power Relay					1	.026	*	.026	
									.197
TELEMETERING FUNCTION									
FM/FM Transmitter		4	16	20	7	.191	.3	.057	
Power Amplifier	1		6	5	4	.650	.3	.195	
Power Amplifier Relay					1	.018	*	.018	
Transmitter Band-Pass filter				2	2	.006	.3	.002	
Antenna Relay					1	.0001	*	.0001	
Receiver Band-Pass Filter				2	2	.006	.3	.002	
FM Receiver		14	45	46	15	.606	.3	.182	
Subcarrier Discriminator		1	2	4	5	.049	.3	.015	
FM Subcarrier Oscillator		2	7	10	3	.091	.03	.003	
									.47
TELEVISION FUNCTION									
Television Camera Chain	5	27	92	39	7	4.40	.3	1.32	
Tape Storage Read-in	5	11	58	34	4	2.09	.3	.627	
Tape Storage Read-out	7	16	81	48	4	2.92	.3	.876	
Modulator-Transmitter	2	9	36	20	14	1.05	.3	.315	
									3.14
BEACON FUNCTION									
Beacon Receiver		3	8	3	2	.127	.3	.038	
Beacon Modulator and Transmitter	4	14	51	19	23	6.24	.3	1.87	
									1.91
ATTITUDE STABILIZATION FUNCTION									
Attitude Stabilizer (3 units)	3	3	6		6	1.39	1.0	1.39	
									1.39
GRAND TOTALS	27	108	422	261	102				7.11
ADJUSTED GRAND TOTAL FAILURE RATE (includes allowance of 25% for parts peculiar)									8.89

*Basic failure rate for relays includes duty-factor (operates per hour)

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SUMMARY OF COMPONENTS AND FAILURE RATES FOR GROWTH STAGE III

Unit	Component Populations: Tubes	Transistors	Resistors	Capacitors	Misc.	Failure Rate %/1000 hrs	Duty Factor	Adjusted Failure Rate %/1000 hrs.
MONITOR FUNCTION		4	14	9	2	.065	1.0	.065
TELEMETERING FUNCTION	1	21	76	89	40	.687	.3	.206
TELEVISION FUNCTION	19	63	267	141	29	6.00	.3	1.80
BEACON FUNCTION	4	17	59	22	25	2.87	.3	.861
ATTITUDE STABILIZATION FUNCTION		15	6		6	.235	1.0	.235
GRAND TOTALS	24	120	422	261	102			3.17
ADJUSTED GRAND TOTAL FAILURE RATE (includes allowance of 25% for parts peculiar)								3.96

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CIRCUIT FUNCTIONS AND FAILURE-RATE ANALYSIS

Assumed Component Ambient Temperature: 55°C

Component Name	Component Type	Circuit Function	No. Used	Electrical and/or Mechanical Stress	Failure Rate Per component %/1000 hrs	Failure Rate for all Components %/1000 hrs
MONITOR RECEIVER (100 mc)						
Transistor		Video Amplifier	1		.1	.1
		Multivibrator	2		.1	.2
		Power Amplifier	1		.1	.4
		Total	4			.4
Resistor, Fixed	RC	Emitter Resistor	3	0.1	.011	.033
	RC	Base Resistor	3	0.1	.011	.033
	RC	Voltage Divider	1	0.1	.011	.011
	RC	Collector Resistor	4	0.1	.011	.044
	RN	RC Timing	2	0.1	.011	.022
	RN	RC Filter	1	0.1	.011	.011
		Total	14			.154
Capacitor, Fixed	CP	Coupling Capacitor	3	0.1	.00045	.0014
	CM	RC Timing	2	0.1	.0007	.0014
	CT	Emitter by Pass	2	0.8	.012	.0240
	CM	RC Filter	2	0.1	.0007	.0014
		Total	9			.0282
Crystal Diode	Silicon	Detection	1	0.1	.075	.075

[redacted]

Circuit References

1. RCA TV Transistor Camera Chain developed for ARS
2. Shea, Richard F., "Principles of Transistor Circuits", John Wiley and Sons, 1953
3. Krugman, Leonard, "Fundamentals of Transistors", Rider, 1954
4. Bell System Symposia, "The Transistor", 1951

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CIRCUIT FUNCTIONS AND FAILURE-RATE ANALYSIS

Assumed Component Ambient Temperature: 55°C

Component Name	Component Type	Circuit Function	No. Used	Electrical and/or Mechanical Stress	Failure Rate per component %/1000 hrs.	Failure Rate for all Components %/1000 hrs.
POWER RELAY						
Relay	Power	Power Bank Operation	1	6/1	.13*	.13

*Consists of basic failure rate (0.1) plus supplementary (stress) failure rate (.02 per contact set)

Component Name	Component Type	Circuit Function	No. Used	Electrical and/or Mechanical Stress	Failure Rate per component %/1000 hrs.	Failure Rate for all Components %/1000 hrs.
FM/FM TRANSMITTER						
Tube	Subm.Pentode	Reactance Modulator	1	.7	1.2	1.2
	Subm.Triode	Oscillator	1	.7	.7	.7
	Subm.Triode	Frequency Doubler	1	.7	.7	.7
	Min.Pentode	Power Amplifier	1	.9	.9	.9
		Total	3			3.5
Resistor, Fixed	RC	RC Network	1	0.2	.012	.012
	RC	Screen Resistor	2	0.6	.015	.030
	RC	Voltage Division	3	0.4	.014	.042
	RC	Filament Circuit Filtering	2	0.6	.015	.030
	RC	Grid Resistors	3	0.1	.011	.033
	RC	Plate Resistors	2	0.6	.015	.030
	RC	Cathode Resistors	3	0.1	.011	.033
		Total	16			.210
Capacitors, Fixed	CM	RC Network	1	0.2	.0009	.0009
	CM	RF Filter	3	0.5	.003	.009
	CM	Screen By-Pass	2	0.5	.003	.006
	CM	Cathode By-Pass	3	0.1	.0007	.0021
	CM	Plate By-Pass	2	0.7	.0075	.0150
	CM	Coupling and/or Blocking	3	0.3	.0014	.0042
	CM	Oscillator Tank Circuit	1	0.4	.0019	.0019
	CC	Filament By-Pass Filter	3	0.1	.0014	.0042
Capacitors, Variable	CV	RF Freq. Tuning	2	0.1	.0014	.0028
		Total	20			.0461

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CIRCUIT FUNCTIONS AND FAILURE-RATE ANALYSIS

Assumed Component Ambient Temperature: 55°C

Component Name	Component Type	Circuit Function	No. Used	Electrical and/or Mechanical Stress	Failure Rate per component %/1000 hrs.	Failure Rate for all Components %/1000 hrs.
FM/FM TRANSMITTER, contd.						
Coils		Osc. Tank Circuit	1	0.2	.014	.014
		LC Filter	3	0.5	.015	.045
		RF Freq. Tuning	3	0.3	.014	.042
		Total	7			.0101

Circuit References

1. Raymond Rosen Engineering Products Type 840 Transmitter, RREP, Equipment Specifications Catalog.

Component Name	Component Type	Circuit Function	No. Used	Electrical and/or Mechanical Stress	Failure Rate per component %/1000 hrs.	Failure Rate for all Components %/1000 hrs.
POWER AMPLIFIER						
Tube	JAN 5894	Power Amplifier	1	.8	2.0	2.0
Capacitors, Variable	CV	Grid Tuning	2	.1	.0014	.0028
	CV	Plate Tuning	2	.5	.0090	.0180
	CV	Output Tuning	1	.1	.0014	.0014
		Total	5			.0222
Coils, RF		Plate, Screen, and Cathode Circuits	3	.5	.015	.045
Resistors, Variable	RV	Screen Resistor	1	.2	.012	.012
Resistors, Fixed	RB	Cathode Resistor	1	.5	.033	.033
	RC	Grid Signal Balance	3	.1	.011	.033
	RC	Grid Resistor	1	.1	.011	.011
		Total	5			.089

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CIRCUIT FUNCTIONS AND FAILURE-RATE ANALYSIS

Assumed Component Ambient Temperature: 55°C

Component Name	Component Type	Circuit Function	No. Used	Electrical and/or mechanical Stress	Failure Rate per component %/1000 hrs	Failure Rate for all components %/1000 hrs.
POWER AMPLIFIER, contd.						
VHF Plumbing		Signal transfer				
RF Interference Filter	6 sections*	To Minimize Conducted and radiated Interference	1	.5 (1 sec) .2 (5 sec)	.020 .015	.020 .075
		Total	1			.095

*Each section consists of 2 capacitors and 1 coil.

Circuit References

1. Applied Science Corporation of Princeton, Model DPA-1, ASCOP Equipment Specification Bulletin D1-1

Component Name	Component Type	Circuit Function	No. Used	Electrical and/or mechanical Stress	Failure Rate per component %/1000 hrs	Failure Rate for all components %/1000 hrs.
POWER AMPLIFIER RELAY						
Relay	Power	Power Ampl. Relay	1	4/1	.09*	.09

*Consists of basic failure rate (0.1) plus supplementary (stress) failure rate (0.2 per contact set)

Component Name	Component Type	Circuit Function	No. Used	Electrical and/or mechanical Stress	Failure Rate per component %/1000 hrs	Failure Rate for all components %/1000 hrs.
TRANSMITTER BAND-PASS FILTER						
Coil, RF		LC Tank Filter	2	.1	.014	.028
Trimmer Cap.	CV	LC Filter	2	.1	.0014	.003
ANTENNA RELAY						
Relay	Power	Antenna selection	1	2/1*	.0005*	.0005

*The Failure Rate consists of the basic rate (0.1) plus the supplementary (stress) rate (0.2 per contact set). Also since the relay must operate only once during the life of the equipment, the failure rate has been reduced by a factor of 0.01.

Component Name	Component Type	Circuit Function	No. Used	Electrical and/or mechanical Stress	Failure Rate per component %/1000 hrs	Failure Rate for all components %/1000 hrs.
RECEIVER BAND-PASS FILTER						
Coil, RF		LC Tank Filter	2	.1	.014	.028
Trimmer Cap.	CV	LC Filter	2	.1	.0014	.003

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CIRCUIT FUNCTIONS AND FAILURE-RATE ANALYSIS

Assumed Component Ambient Temperature: 55°C

Component Name	Component Type	Circuit Function	No. Used	Electrical and/or Mechanical Stress	Failure Rate per component %/1000 hrs.	Failure Rate for all Components %/1000 hrs.
FM RECEIVER (225 Mc)						
Tube	Subm. Tri.	RF Ampl. (225MC)	2	.7	.9	1.8
	1/2 Subm. Tri.	Crystal Oscillator		.7	.7	.7
	1/2 Subm. Tri.	Freq. Multiplier	1	.7	.7	.7
	1/2 Subm. Tri.	First Mixer		.7	.7	.7
	1/2 Subm. Tri.	IF Ampl. (30MC)	1	.7	.7	.7
	Subm. Pentode	IF Ampl. (30MC)	3	.7	1.2	3.6
	1/2 Subm. Tri.	Second Mixer		.7	.7	.7
	1/2 Subm. Tri.	Crystal Oscillator	1	.7	.7	.7
	Subm. Pentode	Limiter	3	.7	1.2	3.6
		Total	11			13.2
Capacitors, Fixed	CM	Cathode By-Pass	5	.1	.0007	.0035
	CM	Plate	8	.4	.0019	.0152
	CC	Interstage coupling	11	.3	.004	.044
	CM	LC Tank Circuit	2	.3	.0012	.0024
	CM	Series LC Filter	3	.1	.0007	.0021
	CM	Screen By-Pass	3	.2	.0009	.0027
	CM	Grid Leak Bias Cap.	3	.1	.0007	.0021
		Total	35			.0720
Capacitors, Variable	CC	LC Filter	2	.1	.0015	.0030
	CC	Trimmer Cap	6	.1	.0015	.0090
	CC	RF Tuning	1	.1	.0015	.0015
	CC	LC Tank Circuit	2	.1	.0015	.0030
		Total	11			.0165

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CIRCUIT FUNCTION AND FAILURE-RATE ANALYSIS

Assumed Component Ambient Temperature: 55°C

Component Name	Component Type	Circuit Function	No. Used	Electrical and/or Mechanical Stress	Failure Rate per Component %/1000 hrs.	Failure Rate for all Components %/1000 hrs.
FM RECEIVER (225 MC) contd.						
Resistors, Fixed	RC	Cathode Resistor	5	.2	.012	.060
	RC	Grid I Limiting	1	.1	.011	.011
	RC	Plate Load Resistors	11	.4	.014	.154
	RC	Grid Input	8	.1	.011	.088
	RC	Screen Resistors	6	.3	.013	.078
	RC	Plate De-Coupling	8	.2	.012	.096
	RC	Grid leak Bias	3	.1	.011	.033
	RC	Voltage Divider Network	3	.2	.012	.036
		Total	45			.556
Coils, VHF		Antenna Coupling	1	0.1	.014	.014
		Cathode Filter	1	0.3	.014	.014
		Parallel LC Filter	2	0.1	.014	.028
		Series LC Filter	3	0.1	.014	.042
		LC Tank Circuit	2	0.1	.014	.028
		Total	9			.126
Crystal	Quartz	Oscillator	2	0.4	.050	.100
Transformer		Coupling	3	0.2	.015	.045
		Impedance Matching	1	0.2	.015	.015
		Total	4			.060

Circuit References

1. Raymond Rosen Engineering Products Report No. 459 and Model 842C RREP Equipment Specification Catalog
2. Weather Station Telemetering Equipment Memorandum Report by Montgomery, G. F., of Central Radio Propagation Laboratories of the National Bureau of Standards
3. Langford-Smith, F. "Radiotron Designer's Handbook", Wireless Press, 1952.

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CIRCUIT FUNCTIONS AND FAILURE-RATE ANALYSIS

Assumed Component Ambient Temperature: 55°C

Component Name	Component Type	Circuit Function	No. Used	Electrical and/or Mechanical Stress	Failure Rate per Component %/1000 hrs.	Failure Rate for all Components %/1000 hrs.
SUBCARRIER DISCRIMINATOR						
Tube	Subm. Tri.	Cathode Follower	1	.7	.9	.9
Capacitors, Fixed	CP	LC Filter	4	.1	.00045	.0018
Coils		LC Filter	5	.1	.014	.070
Resistors, Fixed	RC	Grid Resistor	1	.1	.011	.011
	RC	Cathode Resistor	1	.4	.014	.014
		Total	2			.025

Circuit References

1. Henney, Keith, "Radio Engineering Handbook", McGraw Hill, 1950.

2. Guillemin, E. A., "Communication Networks", J. Wiley and Sons, 1931 - 1935.

3. Chance, et al, "Waveforms", MIT Radiation Laboratory Series, McGraw Hill, 1949.

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CIRCUIT FUNCTIONS AND FAILURE-RATE ANALYSIS

Assumed Component Ambient Temperature: 55°C

Component Name	Component Type	Circuit Function	No. Used	Electrical and/or Mechanical Stress	Failure Rate per Component - %/1000 hrs.	Failure Rate for all Components %/1000 hrs.
TELEVISION CAMERA CHAIN						
Transistor	SB100	Vidicon Preamp	1	0.5	.1	.1
	SB100	Video Amplifiers	4	0.5	.1	.4
	2N78	Keyed Clamp	1	0.5	.1	.1
	2N43	Clamp Driver and Pulse Inv.	1	0.5	.1	.1
	2N101	Vert. Defl. Ampls.	2	0.5	.1	.2
	TI905	Vert. Sawtooth Gen	1	0.5	.1	.1
	TI905	Vert. Saw Driver	1	0.5	.1	.1
	TI905	Vert. Rate Gen.	1	0.5	.1	.1
	2N43	Vert. Rate Gen.	1	0.5	.1	.1
	2N35	Hor. Vert.Blanking Mixer	1	0.5	.1	.1
	2N101	Hor. Defl. ampls.	2	0.5	.1	.2
	2N43	Hor. Driver	1	0.5	.1	.1
	2N43	Hor. Sawtooth Gen.	1	0.5	.1	.1
	2N35	Hor. Rate Gen.	1	0.5	.1	.1
	2N43	Hor. Rate Gen.	1	0.5	.1	.1
	2N43	DC to AC Conversion	2	0.5	.1	.2
		Total	22			2.2
Tube	6326	Camera Tube	1	1.0	2.0	2.0
Resistors, Fixed	RC	Base Resistors	16	0.1	.011	.176
	RC	Collector Resistors	13	0.1	.011	.143
	RC	Emitter Resistors	22	0.1	.011	.242
	RC	Voltage Dividing	14	0.1	.011	.154
	RC	Keyed Clamp Bridge Ntwk.	2	0.1	.011	.022
	RC	RC Networks	3	0.1	.011	.033
Resistors, Variable	RV	Gain Control	1	0.1	.011	.011
	RV	Set DC Level for Keyed Clp.	1	0.1	.011	.011
	RV	Vert Size	1	0.1	.011	.011
	RV	DC Level for Vert. Rate	1	0.1	.011	.011
	RV	Hor. Size	1	0.1	.011	.011

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CIRCUIT FUNCTIONS AND FAILURE-RATE ANALYSIS

Assumed Component Ambient Temperature: 55°C

Component Name	Component Type	Circuit Function	No. Used	Electrical and/or Mechanical Stress	Failure Rate per component %/1000 hrs.	Failure Rate for all Components %/1000 hrs.
TELEVISION CAMERA CHAIN(contd)						
Resistors, Variable	RV	DC Level for Horiz. Rate	1	0.1	.011	.011
	RV	Volt. Dividing of Pwr.Sply	5	0.1	.011	.055
	RV	Vert. Centering	1	0.1	.011	.011
	RV	Hor. Centering	1	0.1	.011	.011
		Total	83			.913
Capacitors, Fixed	CT	Emitter By-Pass	4	0.8	.025	.100
	CT	Coupling and Blocking	13	0.8	.025	.330
	CP	Filter (350 v pwr sply)	2	0.8	.012	.024
	CC	Part of RC netwk (for Filter, Integr.or Diff.)	5	0.1	.0014	.007
		Total	24			.461
Diodes	T7G	Keyed Clamp Bridge	2	0.1	.075	.150
	HD6006	Clamping	2	0.1	.075	.150
	CK739	Clamping	2	0.1	.075	.150
	IN209	Sil.Volt.Ref. Diodes	1	0.1	.075	.075
	IN211	Sil.Volt.Ref. Diodes	1	0.1	.075	.075
	IN219	Sil. Volt.Ref.Diodes	1	0.1	.075	.075
	IN222	Bridge Rectifier	4	0.1	.075	.300
		Total	13			.975
Transformers	Iron Core Power	Power, Step-UP	1	0.6	.018*	.018
Yoke		Vert.Defl. Yoke	1	0.8	.05	.05
		Horiz. Defl. Yoke	1	0.8	.05	.05
		Total	2			.10

*Based on 40°C temperature rise above ambient

Circuit References

RCA TV Transistor Television Camera Chain developed for ARS.

CIRCUIT FUNCTIONS AND FAILURE-RATE ANALYSIS

Assumed Component Ambient Temperature: 55°C

Component Name	Component Type	Circuit Function	No. Used.	Electrical and/or Mechanical Stress	Failure Rate Per component %/1000 hrs.	Failure Rate for all Components %/1000 hrs.
FM SUBCARRIER OSCILLATOR (1.3 kc to 22kc)						
Tube	Subm. Tri.	Oscillator	1	.7	.9	.9
	Subm. Tri.	Cathode Follower	1	.7	.9	.9
		Total	2			.18
Resistor, Fixed	RC	Grid Resistors	3	.1	.011	.033
	RC	Plate Load	1	.4	.014	.014
	RC	Voltage Divider	2	.1	.011	.022
Resistor, Var.	RA	Cathode Resistor	1	.4	.034	.034
		Total	7			.103
Capacitor, Fixed	CM	Coupling	2	.2	.0009	.0018
	CM	Tank Circuit	2	.1	.0007	.0014
	CC	Feedback Coupling	1	.1	.0014	.0014
	CC	Low Pass Filter	5	.1	.0014	.0070
		Total	10			.0116
Coil		Low Pass Filter	2	.2	.014	.028
Coil, Var.	Pwd. Iron Core	Tank Circuit (pickup coil)	1	.2	.014	.012
		Total	3			.040

<u>Circuit References</u>

1. Raymond Rosen Engineering Products Model 874, RREP Equipment Specification Catalog.

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CIRCUIT FUNCTIONS AND FAILURE-RATE ANALYSIS

Assumed Component Ambient Temperature: 55°C

Component Name	Component Type	Circuit Function	No. Used	Electrical and/or Mechanical Stress	Failure Rate per component %/1000 hrs.	Failure Rate for all Components %/1000 hrs.
BEACON RECEIVER (C-Band)						
Tube	Subm. Pentode	Video Amplifier	1		1.2	1.2
	Subm.Dual Tri.	Cathode Follower	1		1.4	1.4
		Total	2			2.6
Resistors, Fixed	RC	Grid Resistors	3	0.1	.011	.033
	RC	Cathode Resistors	2	0.2	.012	.024
	RC	Plate Resistors	1	0.4	.014	.014
	RN	Volt. Divider for Fixed Bias	2	0.2	.012	.024
		Total	8			.095
Crystal Diode	Silicon	Crystal Detector	1	0.1	.075	.075
Transformer		Impedance Matching	1	0.1	.015	.015
Fixed Capacitor	CP	Coupling	2	0.2	.0007	.0014
	CP	Cathode By-Pass	1	0.2	.0007	.0007
		Total	3			.0021

Circuit References

1. Robert, Arthur, "Radar Beacons", MIT Radiation Laboratories Series, McGraw Hill, 1947.
2. NAVAER 16-1-519 "Handbook of Preferred Circuits for Navy Aeronautical Electronic Equipment" (Sept. 1955)

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CIRCUIT FUNCTIONS AND FAILURE-RATE ANALYSIS

Assumed Component Ambient Temperature: 55°C

Component Name	Component Type	Circuit Function	No. Used	Electrical and/or Mechanical Stress	Failure Rate per component %/1000 hrs.	Failure Rate for all Components %/1000 hrs.
BEACON MODULATOR AND TRANSMITTER (C-Band, 3900 - 6200 MC)						
Tube	Subm.Dual Tri	Multivibrator	1	.7	1.4	1.4
	Subm.Dual Tri	Cathode Follower	1	.7	1.4	1.4
	Subm.Dual Tri	Blocking Oscillator Driver	1	.7	1.4	1.4
	Min.Dual Tri.	Switch Tube	1	.7	1.0	1.0
	BL 212	Magnetron	1	1.0	5.0	5.0
	1B63A	TR Tubes	2	1.0	5.0	10.0
	1/2 Subm.Dual Tri.	Amppifiers	4	.7	.5	2.0
	Min.Dual Tri.	Magnetron Tuning Motor Control	1	.7	1.0	1.0
		Total	12			23.2
Ref. Cavity		Beacon Freg.Reg.	1	1.0	.5	.5
Resistor, Fixed	RC	Screen Resistor	6	.3	.013	.078
	RC	Plate Resistor	15	.4	.014	.210
	RC	Cathode Resistor	8	.2	.012	.096
	RC	Current Limiting	5	.1	.011	.055
	RC	RC Decoupling Filter	4	.1	.011	.044
	RC	Grid Resistor	10	.1	.011	.110
Resistor, Var.	RA	Adj. Pulse Length	1	.1	.011	.011
	RV	Gain Adj. (Ampl.)	2	.1	.011	.022
		Total	51			1.126

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CIRCUIT FUNCTIONS AND FAILURE-RATE ANALYSIS

Assumed Component Ambient Temperature: 55°C

Component Name	Component Type	Circuit Function	No. Used	Electrical and/or Mechanical Stress	Failure Rate per component %/1000 hrs.	Failure Rate for all Components %/1000 hrs.
BEACON MODULATOR AND TRANSMITTER (C-Band, 3900-6200 Mc)						
Capacitor, Fixed	CM	Screen By-Pass	2	.3	.0014	.0028
	CM	Coupling Capacitor	5	.5	.003	.015
	CM	Cathode By-Pass	2	.1	.0007	.0014
	CP	RC Decoupling Filter	4	.5	.0027	.0108
	CT	Vibrator Input Filter	1	.7	.012	.012
	CP	ARC Suppression	2	.5	.0027	.0054
	CP	Power Supply Filter	2	.5	.0027	.0054
Capacitor, Var.	CV	Coupling (RC variation)	1	.2	.0022	.0022
		Total	19			.0550
Coil		Pulse Shaping	3	.5	.015	.045
		Magnetron Circuit	1	.5	.015	.015
		Total	4			.060
Choke (Iron Core)		Vibrator Input Filter	1	.6	.07*	.07
Transformer		Blocking Osc. Pulse Trans.	1	.8	.07*	.07
		Magnetron Pulse Trans.	1	.8	.07*	.07
		Power Transf.	1	.8	.08**	.08
		Audio Amplifier Trans.	4	.3	.06***	.24
		Total	7			.46
Silicon Crystals	IN23B	Crystal Detector	2	.1	.075	.075

*Based on 25°C rise above ambient temperature

**Based on 50°C rise above ambient temperature

***Based on 10°C rise above ambient temperature

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CIRCUIT FUNCTIONS AND FAILURE-RATE ANALYSIS

Assumed Component Ambient Temperatures: 55°C

Component Name	Component Type	Circuit Function	No. Used	Electrical and/or Mechanical Stress	Failure Rate per component %/1000 hrs.	Failure Rate for all components %/1000 hrs.
BEACON MODULATOR AND TRANS-MITTER (C-Band, 3900-6200MC)						
Crystal Diode	Silicon	Diode Rectifier	4	.6	.10	.40
Rectifier	Selenium	Power Supply Rect.	2	.8	.15	.30
Vibrator		H.V. Power Supply	1	.7	2.0	2.0
Tuning Motor		Magnetron Tuning	1	.1	.1	.1

Circuit References

1. Roberts, Arthur, "Radar Beacons", Radiation Laboratory Series, McGraw Hill, 1947.

2. Langford-Smith, F., "Radiotron Designer's Handbook", Wireless Press, 1952.

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CIRCUIT FUNCTIONS AND FAILURE-RATE ANALYSIS

Assumed Component Ambient Temperature: 55°C

Component Name	Component Type	Circuit Function	No. Used	Electrical and/or Mechanical Stress	Failure Rate per component %/1000 hrs.	Failure Rate for all components %/1000 hrs.
ATTITUDE STABILIZERS*						
Tube	6080 WA	Control Amplifier	1	.5	1.0	1.0
	5687 WA	Dynamic Brake	1	.4	.7	.7
		Total	2			1.7
Resistor	RC	Grid Resistor	1	0.1	.011	.011
	RC	Cathode Resistor	1	0.2	.012	.012
		Total	2			.023
Tachometer		Feedback Control	1	0.4	.005	.005
Motor	DC	Reaction Wheel Drive	1	0.4	.10	.10

*3 Units required - 1 for each axis of stabilization.

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CHAPTER IX

COMPONENT CONSTRUCTION AND SELECTION TECHNIQUES

A. INTRODUCTION

This chapter contains a rather general discussion of possible plans for obtaining improved reliability through manufacturing process control and parts selection procedures. The first plan applies where the usual product is very close to being sufficiently reliable; this plan depends largely upon more stringent inspection techniques and analysis of failures. The second plan applies where much more reliable operation is required than is currently afforded by existing equipment; this plan calls for very stringent process control in all phases of the manufacture, special training for personnel involved in the manufacture, very severe and thorough inspection, large-scale testing, and careful analysis of every failure in order to improve the process control.

B. A PLAN FOR OBTAINING MODERATE IMPROVEMENT OF COMPONENT RELIABILITY

1) Establish comprehensive purchase specifications and rigidly enforce them.
2) Prepare and enforce strict manufacturing specifications. Degradation often occurs in the equipment assembly process.
3) Screen potential vendors by careful inspection of their production and quality control facilities. This would include inspection of items produced in a manner similar to that for the proposed contract.

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4) Establish qualified production lists based on meeting prescribed standards.

5) Conduct both periodic and non-scheduled requalification tests. When possible, the test samples should be selected from the purchaser's stock.

6) Require the vendor to report any planned change in component material or in manufacturing process so that a new evaluation of the component may be made prior to its use in equipment.

7) Monitor and analyze field failure information to establish the cause of failure, to find remedial techniques, and to decide if vendor qualification should be withdrawn.

8) Utilize more protective sampling inspection procedures. Inspection of a sample by variables, where applicable, generally affords more complete information on the quality of the lot than the same size sample inspected by attributes. In any case it is possible to specify excellent sequential sampling plans for inspection either by attributes or variables.

9) Make increasing use of statistical sampling techniques for both destructive and nondestructive tests of components, subassemblies, and complete systems.

10) Be sure that a component is suitable for the specific application in which it is to be used. A large percentage of field failures are caused by misapplication.

C. A PLAN FOR OBTAINING EXTREMELY RELIABLE COMPONENTS

1) Use only vendors with a background of many years of proven integrity.

2) Specify not only component performance requirements but design and manufacturing process requirements as well.

3) Require if necessary dust free, temperature and humidity controlled, and exceptionally clean factories.

4) Where possible, develop automatic manufacturing and testing facilities.

5) Monitor every step in the production of parts from the selection of materials to the final assembly.

6) Carefully train all operators, inspectors and supervisors.

7) Employ exceptionally rigid sampling inspection plans calling for such procedures as recycling items through non-destructive tests, use of increased stringency tests to failure, life testing in excess of the time required for operation when feasible and accelerated life tests when valid. Marginal checking procedures should be used on 100 percent of the items when meaningful.

8) Analyze every failure, whether it occurred in the field or during factory inspection, to determine the cause of failure and the necessary remedial steps.

D. SOME REMARKS ABOUT THE TWO PLANS

The first plan assumes that, if the vendor knows precisely the requirements to be met, the threat of disqualification will be sufficient to force him to maintain standards and that a somewhat more stringent inspection sampling is all that is required to prevent an unsatisfactory lot from being accepted. If either of these assumptions is false, a plan such as this can result in lots being accepted only very infrequently. Such plans are common in the production of missile electronic equipment.

The second plan assumes that the way to assure reliability is to utilize conservatively designed items in very carefully controlled manufacturing processes and to insure the quality of the final product by conducting very protective sampling inspection techniques. This type of plan was utilized in manufacturing the repeaters for the underwater telephone cable.

E. AN EXAMPLE OF A POSSIBLE COMPONENTS TEST

Testing must establish that a component is able to withstand the stresses of ascent and then to operate for the required length of time. To instrument such a test on the ground requires that a detailed knowledge of the ascent stresses and orbital conditions be obtained very early in the program. With this knowledge as a guide, a large part of each lot could be subjected to simulated ascents. Component performance would be measured before, during (if the component would ordinarily operate during ascent) and after to ascertain the quality and uniformity of the lot. Those lots that performed satisfactorily during the simulated ascent tests would then be placed on life test under simulated orbital conditions. Only those lots that had satisfactory life would then be used in production. If more lots are accepted than are required for production, it is possible to use statistical methods to select the best of these lots.[1,2]

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1 Beckhofer, R. E., Dunnett, C. W., and Sobel, M.: "A Two-Sample Multiple Decision Procedure for Ranking Means of Normal Population with a Common Unknown Variance", Biometrika 41, 170-176 (1954)

2 Sobel, M.: "Statistical Techniques for Reducing Time in Reliability Studies", The Bell System Technical Journal 35 (1956)

This type of testing procedure, when coupled with a thorough analysis of the failures, provides a method of determining the current reliability of the system and the measures that are mecessary to make it more reliable. This is a costly testing procedure but it is undoubtedly considerably less expensive than a series of unsuccessful "shoots".

CHAPTER X

CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

Equipments have been successfully designed for extremely long-life operation - for example, 20 years in the case of the underwater telephone cable repeaters - although none of these long-life designs approach the complexity required in the ARS development. Long life has been achieved in the past through the use of extremely conservative design practice, the use of only components and materials with a long history of satisfactory operation (proven integrity), stringent process control, and extensive testing.

Proven integrity cannot be demanded of many ARS components since the unique environment of the vehicle necessitates the use of components now in the development stage. This places even greater stress on developing adequate process control and extensive testing.

1. High-Population Components

A probability of 0.95 for 500-hour survival of the early vehicle once orbit is attained appears feasible if there is a greater emphasis placed on process control and parts selection. Use of new materials for components and considerable advance in material selection techniques will be required in addition to rigid process controls to meet the longer life required of the later vehicles.

The information on component performance under ascent conditions, though extremely limited, indicates that adequate packaging techniques are available which will enable the components to withstand the thermal shock, the vibration, and the rapid change in pressure encountered in ascent.

The selection of highly reliable individual components and the maintenance of this reliability during assembly and storage prior to launch is a problem requiring careful consideration.

Such special precautions/as the potting of components and using welded rather than soldered connections will be necessary for satisfactory operation of components.

Many components which break down when operated at ordinary ratings will operate satisfactorily if properly derated. Considerable study is needed of the effects of derating on component performance.

2. Components Peculiar to ARS

a. Power Supplies. Various types of batteries and a solar-heated thermocouple have been considered.

(1) "Single-Shot" Batteries. Batteries are available that meet requirements. The main problems are packaging and the interconnection of cells.

(2) Storage Batteries. These batteries would be used in conjuntion with solar batteries. Storage batteries were not tested for this study but the available information indicates that adequate batteries for this application can be obtained with relatively little development effort. In addition to the problems of packaging there are problems in disconnecting the battery charger after each charge cycle.

(3) Solar Batteries. Further development is needed in this area to increase efficiency. Extensive testing under conditions similar to application is required to establish reliability.

(4) Solar-Heated Thermocouples. Further development is needed, particularly with regard to the types of materials used in the thermocouple, to increase efficiency.

b. Picture Tubes. The vidicon and the orthicon have been considered.

(1) Vidicon. Tests on current model vidicons indicate that, with slight modifications, this type of tube should perform satisfactorily. Some effort is required to develop a new target for the vidicon.

(2) Orthicon. Test results have been encouraging. Further development is needed, however.

(3) Night-Viewing Orthicon. This tube is still in the development stage.

c. Recording Systems. Magnetic and electrostatic tape systems were considered.

(1) Magnetic Tape. A substantial amount of development remains to obtain a reliable system.

(2) Electrostatic Tape. This tape is still in the research phase of its development.

d. Microwave Transmitting Tubes. Both the beacon magnetrons and the television transmitter magnetron need further development to attain the life requirements.

e. Traveling Wave Tubes. These tubes might be suitable for ferret applications. However, development of new traveling-wave tubes to meet ferret requirements is required.

3. Test Equipment

a. Vibration Test Equipment. Suitable vibration exciters are commercially available for performing vibration tests in the factory. Tie-down firing tests will probably require use of an installation at one of the proving grounds.

b. Ultra-High Vacuum Chamber. Chambers for obtaining pressure in the range from 10^{-8} to 10^{-9} mm of Hg, for evaluating such items as mass spectrometers and ionization gages, have been built only in the laboratory and are not commercially available.

c. Vacuum Ovens. Vacuum ovens can be obtained commercially that are capable of attaining pressures as low as 10^{-5}mm of Hg and are capable of both heating and refrigeration.

d. Quick Pulldown Chamber. Chambers are commercially available that will drop the pressure to 1 percent of sea level within 100 seconds and 0.1 percent of sea level within 130 seconds.

e. Thermal Radiation Test Equipment. No test equipment of the type recommended in Chapter VI is commercially available.

f. Nuclear Radiation Test Equipment. A complete mockup of the missile structure with payload component in place and in operation is required. The test must be performed in an installation equipped to handle and dispose of radioactively hot materials.

g. Dust Accelerators. Two methods have been suggested. An explosive technique has been instrumented in part and an electrostatic method has been proposed. Neither apparatus is commercially available.

h. Solar Battery Test Equipment. The items comprising equipment for laboratory test with artificial light sources are commercially available. The required outdoor mounting stand can readily be built.

i. Ferret Test Equipment. Microwave signal generators for testing ferret equipment are commercially available.

B. RECOMMENDATIONS

1. General

A comprehensive environmental test program should be started. This program would test components under conditions of ascent environment, orbital environment and the radioactive conditions that will prevail with the use of a nuclear power supply. If valid inferences are to come from this program it is essential that both the engineering and the statistical design of these tests receive very careful consideration. To this end such varied types of environmental information as vibrational characteristics during ascent, temperature profile in ascent and cosmic ray density should be gathered. It is recommended that a central test planning group be set up to 1) assemble the necessary environmental information from various test programs currently in effect 2)on the basis of this environmental information plan,supervise and analyze suitable environmental tests. The planning group should have available to it adequate centralized test facilities including access to a facility capable of carrying out the nuclear tests. A portion of this program, such as nuclear tests, will require mockups of the vehicle at an early date.

A group should be assigned the specific task of analyzing the requirements for components needed to meet the design reliability goals. This group would 1) assist the contractor in assessing the consequences of specific component commitments on system reliability, 2) keep a current roster of preferred materials and parts, and 3) work with vendors in developing components of the required reliability.

Strict process control should be exeercised in the manufacture of components and in the assembly of systems. By process control is meant not only control of the actual manufacture of the component but the selection of material, quality inspection procedures, material and parts storage procedures, and shipping and handling procedures.

4) A study should be pursued of methods performing for accelerated life tests and for predicting life based on marginal testing. Such methods call for considerably better understanding of the physical process of component failure. Within limits it is possible to circumvent this knowledge of the physics of failure by utilizing empirical results based on testing.

2. High-Population Components.

1) Encapsulants and potting materials such as epoxy and isocyanate should be studied. Proper use of such materials will permit better heat transfer and sealing and will improve certain electrical characteristics. Transformers and reactors have recently become available using epoxy resins as the impregnating material followed by casting in the same resin. These components, in addition to smaller size and better heat dissipation, are thought to have excellent hermetic sealing and superior electrical characteristics.

2) The use of new dielectric materials for capacitors should be studied. This study should include:

1) Gaseous dielectrics such as sulphur hexaflouride and flurocarbons at two to three atmospheres.

2) Liquid dielectrics (flourinated)

3) Solid dielectrics such as polyester, lanestrol, synthetic quartz, glass paper, fused silicate paper, reconstituted mica, hot pressed synthetic mica, phosphate bonded talc ferrocube ceramics, ferroelectric ceramics, and chlorinated indans as capacitor impregnant.

3) Precision wire-would resistors are too bulky; it is desirable that precision metal film resistors be developed with an increased rating at higher temperatures.

4) Development of transistors which operate well over a wider range of temperatures is desirable.

5) Development of circuit forming techniques such as welding is needed for the high temperature application.

3. Components Peculiar to ARS.

1) The early vehicles are entirely dependent on the battery supply hence considerable effort should be made to develop sound packaging and interconnection techniques for the battery supply units.

2) The operation of the transponder is essential to successful radar tracking and communications on the early vehicles. It is therefore recommended that the steps be taken to obtain a reliable pulse magnetron.

3) Development of a transmitting tube capable of transmitting television signals at 8000 mc is desirable if the use of a very highly directive beam is considered necessary for security reasons.

4) It is recommended that further developmental effort be put on the vidicon, orthicon, and night-viewing orthicon.

5) More developmental work should be carried on in order to obtain an adequate and reliable magnetic-tape television recording system. The electrostatic tape is still in the research stage. The increased simplicity of a system utilizing this tape makes further efforts toward its development desirable.

6) Some developmental work is required to obtain increased efficiency from solar batteries. Sufficient test data must be gathered to enable an estimate to be made of their performance. Storage cells to be used in conjunction with the solar batteries should be given extensive tests. Battery packaging and interconnection techniques should receive careful consideration.

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> If dry circuits failures are the result of film or semiconducting phenomena, the circuit designer is mis-applying relays when they are used in low level circuits.
>
> If dry circuits failures are the result of some other phenomena such as permanent displacements of contact position or others, the relay designer needs to be better informed.

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> The report examines qualitatively the advantages and disadvantages of various mechanisms for possible use in electro-magnetic relay designs. No attempt has been made to consider the choice of materials. Only the mechanical features are discussed.

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Results of field tests show effect of environmental conditions on tube reliability. How to keep cathode and bulb temperatures within safe limits is discussed. Heat and vibration are the two major environmental factors of long tube life.

"Electron Tube Life and Reliability - Variations of Life Performance with Usage Conditions", Acheson, Marcus A. - Sylvania Electric Products Inc. - 1954

This paper presents a condensed view of some analytical tools that are applicable to problems of equipment design, operation and maintenance. It presents particularly the shapes and nature of tube life curves, and how these vary widely with performance and environmental conditions.

"Techniques for Application of Electron Tubes in Military Equipment", Whitlock, Rex. S. (Wright Air Development Center) WADC Technical Report 55-1 - January 1955

The report presents the application of electron tubes in three parts. First, dealing with the general nature of the properties of electron tubes, second, with consideration of the effect of these properties in circuit design, and third, presenting mechanical, electrical and environmental data on the properties of specific tube types with such related general information as may be applicable for that type.

"Tri Service Preferred Electron Tube list for Guided Missile Use", Anon

"Some Important Characteristics of Tantalum Electrolytic Capacitors", Dzwonczyk, J. G. RCA Engineers Digest - Nov. - Dec. 1955

When designing filters the minimum capacity for adequate filtering at the lowest operation temperature should be used. In selecting capacitors for coupling applications, the magnitude and change in leakage current over operating temperature range should be considered. When a tantalum unit has been idle and voltage is suddenly applied, the leakage will sometimes show discontinuous fluctuation until the unit has stabilized. Because the dissipation factor in tantalum capacitors has a rising characteristic with increase in frequency there is a frequency at which the unit behaves like a pure resistance.

COMPONENTS

"Paper Capacitor First Failures and Their Distribution", Franlin, W.S. (John E. Fast and Co., Chicago, Ill.) - 6th Annual Electronic Component Conference Proceedings - May 1955

This paper describes the results of one of several tests carried on to determine the distribution of early electrical failures and, by the methods of the statistical theory of extreme values, to arrive at a proper voltage rating to attain reliabilities of the order of 99.99%.

"Application of Tantalum Electrolytic Capacitors", Warner, D.F. - IRE, PGCP-4, November 1955

"High-Temperature Foil-Type Tantalum Capacitors", Peck, David B.; Bubriske, Stanley W.; Schroeder, Walter W. Jr. (Sprague Electric Co. - North Adams, Mass) - Electrical Manufacturing - May 1956

These capacitors have been developed for reliable continuous operation at 125 C. Design calls for a rolled tantalum-foil capacitor section, impregnated with a non-aqueous, organic-type electrolyte sealed in a tubular aluminum housing with a special Teflon-rubber triple-spun gasket. Life test data are presented indicating stability and very low leakage current. A predecessor 85-C design is also described. Tests conducted to data have shown that these capacitors will meet all of the requirements of MIL-C-25102 with the added requirement that all 85C ambient tests conditions are replaced by 125 C test conditions.

"A Progress Report on the Twenty-Thousand Hour Aging of Some Semi-Conductor Diodes", Lane, M. C. (National Bureau of Standards, Washington,D.C.) - 6th Annual Electronics Components Conference Proceedings - May 27, 1955

This is a progress report on 350 randomly chosen diodes from different manufacturers. These diodes have so far been aged 20,000 hours and periodic static and dynamic measurements have been made to determine long-term changes in the forward current, reverse current, forward transient response, hysteresis and reverse current creep of each diode.

"Testing Selenium Rectifiers", Pagano, Edward L. - Electronic Design, April 15, 1956 pp 36-39

The useful life of a selenium rectifier is defined as the time required for the output voltage of the unit to decrease to 90% of its original value. This is a function of both the forward and back resistance characteristics and many tests are designed to determine life characteristics by a measure of the resistance characteristics. In these tests care must be taken to permit the reverse characteristics to "form", that is, to permit the reverse leakage current to decrease upon application of voltage, especially where the units have been stored for extended periods.

Initial worth of the rectifier may be established crudely by a DC test of low voltage in the forward direction, resulting in production of a minimum acceptable forward current, followed by a DC test of high voltage in the reverse direction, resulting in a maximum acceptable leakage current. A more significant test is the Dynamic test using an AC circuit of conventional design to measure forward current but placing the rectifiers back to back to measure leakage current. The difficulty here is that the forward characteristic of the rectifier is non-linear and is therefore effected by the impedance of the AC source. In the reverse direction, the leakage current is a composite of the rms currents of both rectifiers. This makes it difficult to separate the good rectifiers from the bad ones. Some of the erroneous readings of this test may be reduced by using an improved circuit employing additional vacuum diodes and rectifier type AC meters. However, the important point to remember is that in tests conducted on rectifiers it has been determined that the initial conditions do not necessarily disclose absolute rectifier quality. It is the rate of change of initial conditions that is the deciding factor.

"Testing One-Quarter Million Transistors", Schul, George R. and Greenbaum, William H. (Sonotone Corp., Elmsford, N. Y.) - American Society for Quality Control, National Convention Transactions, 1955 - pp 559

"Performance of Selenium Rectifier at High Temperatures", Bechtold, N.F.; Morris, E. W. (Signal Corps Engineering Labs, Fort Monmouth, N. J.) - Electrical Manufacturing - May 1956

The results reported here present rerating curves and also delineate various patterns of failure, with the ratio of input a-c current to reverse leakage current as the chief criterion of comparative performance. This particular investigation has established the existence of two distinct failure patterns which are independent of plate type (conventional or high temperature) and selenium application process (pressed powder, evaporation or molten dip), but peculiar to products of specific manufacturers.

"Determination of Transformer Life", Hamilton, R.L. and Walter, G.E. (G.E. Co., Fort Wayne, Ind.) - Proceedings - 1954 Electronic Components Symposium - Washington, D. C.

To obtain satisfactory life for a transformer, three problems should be solved: (1) the electronic equipment manufacturer or user should define satisfactory "life", (this is customarily the length of time that some percentage of the equipments manufactured should maintain a satisfactory level of operation under the prevailing operating conditions); (2) realistic quantitative values for the operating conditions that the transformers will encounter in the equipment should be established; (3) the supplier needs to predict accurately the effect of these specified operating conditions on the transformers.

To develop a life-test technique for transformers, information is used that is derived from controlled life testing, applying techniques involved specifically for transformers. The three segments of this program are (1) operation of the life test, (2) reduction of data obtained to quantitative results, (3) extrapolation of these results to values of operating conditions other than those actually used in the particular tests.

At present, statistical analysis is being used to determine the confidence limits for present procedures. These limits indicate the reliability or accuracy of the results. Statistical analysis is also being used to determine optimum number of units per set, optimum number of units per group, optimum selection of test temperature values.

"Life Expectancy Tests for Transformers", Lockie, A.M. (Westinghouse Electric Corp. Sharon, Pa.) - Electrical Engineering, AIEE - Jan 1956

A means of obtaining the necessary life-expectancy data is through some form of functional testing, which will require the establishment of an accelerated-aging procedure and a test to determine when the nominal end point of life has been reached. It is suggested that the basic life-expectancy test consist of daily loading at 300% of rating for one hour, 150% of rating for 7 hours, and no load for 17 hours. This loading is repeated for 5 days and followed by an end-point test, including shortcircuit tests at 15 times normal current for 2 seconds, standard impulse tests, and dielectric and induced-potential tests at 65% of the standard values for new apparatus. The combination of loading and end-point tests constitutes one aging cycle, and the nominal life expectancy of the tested structure is expressed as the number of these cycles endured before failure. Data for computing life expectancy on other load cycles can be done by means of an aging-rate curve which shows as a function of temperature, the relative speed with which the structure reaches the selected end point of its life.

The procedures provide both a means of determining the relative life expectancy of different structures and a method of computing the effect of life expectancy on various forms of loading.

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"Revised MIL Spec. for Transformers", Wiler, Edward - Electrical Manufacturing - April 1956 - p 103

Requirements of MIL-T-27A revised to reflect changes in service requirements and availability of new materials. No other significant information given in paper.

"Evaluation of a Proposed Method for Accelerated Testing and Predicting the Life of Electromagnetic Relays", American Electronic Laboratories - Final Report

This was a study program centered on the evaluation of step-stress method of testing relays. The only factor treated in this manner was contact current. Relays were checked for (1) Coil Resistance, (2) Insulation Resistance, (3) Contact Resistance, (4) Coil Current, and (5) Operating and Bounce Time. The analyses made do not lead to a firm conclusion; however, they indicate that operating and bounce time was the most significant of the 5 parameters with respect to step stress tests wherein contact current was the variable. It was believed that a favorable test could probably be devised. (Additional data analysis may show more significance or correlation of some parameters).

"An Analysis of the Effects of Severe Environments on Deposited Carbon Resistors", Manolakos, Peter - 6th Annual Electronic Component Conference Proceedings - May 1955.

Tests show that humidity effects on molded, ceramic, and glass encasements are such that resistance changes of less than 0.5% can generally be expected. Dipped and coated resistors, however, will change as much as 150%. Resistors produced by a single manufacturer will vary from batch to batch. An initial change in resistance will occur as a result of electrical loading followed by a more gradual change during the remainder of the test. Under load the resistance deviation steadily increases. There is an indication this trend will continue with time. Deviation of resistance under load life conditions is approximately proportional to temperature ambient.

"Fixed Film Resistor Evaluations", Allen, J.J.

"The Effect of Resistor Tolerance and Stability on Various Circuit", Anon - U.S. Navy Material Laboratory Project Report LP-5842

"Wiresound Resistors", Mapplebeck, R.H. - Electronic Engineering June 1955

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"Some Physics of Dry Circuit Switching", Montague, L.L. (Farnsworth Electronics Co.) - Guided Missile Relay Working Group of the Guidance and Control Panel, U.S. Navy Inter-Bureau Technical Committee, Washington, D. C. - GMRWG report #2 - September 1955.

The normal condition for a metal surface is to be covered with some type of film. An electrical contact is made by breaking this film in one of two ways (1) by high pressure contact, or (2) by fritting or film breakdown under the stress of a strong electric field. Removal of films by other means such as heating is virtually impossible, particularly as applied to relays. In order for contacts to work reliably in the "dry" application, contact materials and operating atmospheres should be carefully selected so that the film formation is reduced as much as possible. Proper gas clean-up appears to be essential, but this may be difficult in practice. Hot outgassing, guttering and selective atmospheres used in conjunction with the noble metals show some promise of functioning reliably in the dry circuit application. Materials used in relay construction should have low vapor pressures at higher temperatures to reduce the possibility of organic gases arising within the sealed enclosure.

"Problems Encountered and Procedures for Obtaining Short-Term Life Ratings on Resistors", Sackett, W.R.Jr. (Battelle Memorial Institute) - IRE transactions on Component Parts - April 1955

Conditioning must be prescribed in any short-term life-test procedure, or even more, that the moisture content in the resistor must be prescribed. A conditioning procedure of 100 hours at 105 ± 5C was specified in the life-rating procedure given. The procedure also specified that a part of the resistors be exposed to moisture under very severe conditions and that life ratings be obtained both on moist and on dry resistors. It was recommended that any coatings present be stressed at the highest likely short-term temperature rating before exposure to moisture. Some of the problems that are encountered in setting up short-term life-test procedures were described Definitions of Life, Variability, Representative Sampling, Combinations of Test Variables and conditioning are pertinent to tests on composition resistors as well as other electronic components and even to their basic materials.

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"A Survey of Environmental Requirements in Electronic Component. Parts Specification", Anon - Tehcnical report #56, Feb. 25, 1954, Vitro Corp. of America, Silver Spring Lab., Contract DA36-034-ORD-1426

"Proposed Research Engineering Tasks for Component and Component Parts in Guided Missile Applications", Kaufman, Joseph - Memo to Guided Missile Relay Working Group, I BTC (Navy) from Joseph Kaufman, DOFL (Army Ordnance) Chairman R and D, GMRWG (Probably issued early in 1956)

> Field experience on components in guided missiles does not correlate with the experience gained on life testing of components purchased under "adequate" MIL specs. The MIL specs are primarily written to obtain components for "long operating life" or "long intermittent life" equipments as used in jet aircraft and do not meet the "short operating life" and "long storage life" conditions of guided missiles. It is the writer's belief that most eletronic component parts, when operated at their recommended electrical parameters, are satisfactory but that they fail to operate or survive when subjected at the same time to a "rationalized" GM environment where time to live is not realistically defined. To combat this the writer proposes a study program to (1)develop equipment (vibration tables, recording devices, computers) to subject component parts to "white" vibration frequencies, recorded from actual flights of similar birds, using computer techniques to determine and apply the transfer function from location of the recording head to actual location of the test component in the final "bird" and correlate this with field experience, getting as much of the study on an analytical basis as possible, (2) determine the transmissibility characteristics of various materials (3) determine the effects of sahpe and configuration (4) determine the effects of heat and shrinkage on component characteristics when components are potted, (5) determine the effectiveness of various cements and their application thickness in holding components in place (6) determine how effective catacombs are as heat sinks when in contact with components, (7) determine the effect of humidity on various encapsulating materials (this has been done), (8) determine the various economic factors involved, (9) correlate go-nogo tests with life tests (10) determine long passive storage characteristics of components (11) determine high temperature properties of dielectrics (12) investigate possible heat sink techniques for potted components (13) determine short life cap. character.

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"Proposed Relay Testing Techniques for Guided Missile Applications", Kaufman, Joseph - Guided Missile Relay Working Group of the Guidance and Control Panel, U.S. Navy Inter-Bureau Technical Committee, Wash. D.C., GMRWG Report No. 1 September 1955

At present there is no direct relation between existing shock and vibration specifications and missile flight environment. Current methods of testing components (particularly relays) depend on exposing the units to discrete frequencies for predetermined periods of time. Similar methods are used in recording flight data. It is proposed that the concept of acceleration per (cycle bandwidth) ½ ($g/\sqrt{CPS} = e_f$) and the definition of the forcing function based on a spectrum of e_f with frequency is more valid. Acceleration per $\sqrt{\text{cycle bandwidth}}$ is also referred to as acceleration spectral density.

Additional topics of discussion include how such a forcing function permits an evaluation of a relay based on time to malfunction, and how it is "readily" used to evaluate the function of the relay under simulated flight conditions. More study is needed to correlate existing experience with this new concept. A brief explanation is given of how such an evaluation can be used by the design engineer to achieve a reliable end product. The proposal does not suggest the elimination of the sweep frequency technique for it is only by this technique that the failure frequencies can be isolated. In addition, it must be realized that the acceleration spectral density spectrum concept of testing requires vibrators that are non-reactive in the test spectrum and require a large excitation level capacity (45g for a 10 to 2000 c/s spectrum and an excitation of 1g per $\sqrt{\text{cycle bandwidth}}$.)

"Progress Report on Reliability of Electronic Equipment", Anon - Prepared by the Ad Hoc Group on Reliability of Electronic equipment - For the Committee on Electronics of the Research and Development Board.

"The Reliability of Airborne Radar", Boodman, David M. - Operations Research for Management - Edited by J.F. McClosky and F.N. Trefethen - 3rd printing, 1956.

This paper deals with the relationship between reliability and complexity. In order to determine this relationship it is necessary to understand the nature of failures in the system, and to establish a measure of complexity. The Operations Evaluation Group has utilized a threefold category of failure types (1) initial failures (2) wearout failure (3) chance or random failure. The rate of incidence

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of chance failures is determined by the severity of environmental conditions. Observed failure rates showed higher failure rates for tubes than for components. Under the same conditions, increased complexity of newer radars, showed them to be less than acceptable for the required durations. Preventative maintenance, replacement, ruggedizing and moderating equipment environment are necessary for improved reliability.

ENVIRONMENTAL

"Feasibility Study for Minimum Weight Radio Instrumentation of a satellite", Anon - Jet Propulsion Laboratory, Calif. Inst. of Tech., Publication No. 48, Sept. 21, 1955 (SECRET)

One way to keep satellite on course is to use a high spin rate (1000 to 1800 rpm). This will cause centripetal accelerations varying from zero at the center to 800g at an axial distance of 10 inches. Temperature conditions in orbit will be -90°F to +180°F on the skin. For radio link, report shows, little power is required, particularly at frequencies below 100 mc, and at these frequencies directional antennas will do little good, particularly if position of satellite is not known. For power, a chemical battery (one pound) is concluded to be feasible. Report gives theoretical derivation of skin temperature for spherical vehicle and the following references:

"A Feasibility Study of the High Velocity Stages of a Minimum Orbiting Missile", Anon - J.P.L., Calif. Inst. of Tech., Publication No. 47.

"Galactic Radiation at Radio Frequencies, Part V, The Sea Interferometer", Bolton, J.B. and Slee, O.B. Autralian Journal of Applied Physics, 6(4), 1953

"Physics of the Stratosphere", Goody, R.M. - New York, Cambridge University Press, 1954

"Thermal Evaluation of Air-Cooled Electronic Equipment", Robinson, W., Zimmerman - Ohio State University, AF Tech. rept. 6579 Sept. 1952 - Supplement #1 - Aug. 1953

"Efficient Heat Removal ... A Key to Reliability", Schrieber, O.P. (Metal Textile Corp. Roselle, N.J.) - Electronic Equipment, January 1956

Knitted-metal wire gives a tube sleeve efficient heat-removing qualities and also protects tube against shock. As applied in airborne equipment, direct contact is made from tube clamp to case rather than chassis for maximum heat conduction.

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"A Feasibility Study of the High Velocity Stages of a Minimum Orbiting Missile", Anon, - Jet Propulsion Laboratory, Calif. Inst. of Tech., Publication No. 47

"Estimating Temperature Rises in Electronic Equipment Cases," Bibbero - Proc. IRE 39; 504-508, May 1951

"Environmental Design of Electronic Equipment (Corporal)", Comuntzis, Marcus, G. - Jet Propulsion Lab., Calif. Inst. of Tech., Progress Report No. 20-249, Feb. 7, 1955 (CONFIDENTIAL)

> The report suggests that the ambient temperature reached in Corporal is about 135°F in about 30 minutes. The main shock and vibration effects were observed in the 100 to 200 c/s. The main redesign effort has therefore gone into modifying heat sinks to take care of the temperature problem. The result has been a design similar to Melpar's beacon design.

"Guide for the Preparation of Test Procedures for the Thermal Evaluation of Insulation Systems for Electric Equipment", Anon - Prepared by - Working Group of AIEE Coordinating Committee #4 to be considered for inclusion in AIEE Standard No. 1 AIEE Conference Paper - Feb. 1956 - CP-56-386.

"A Survey of Environmental Requirements in Electronic Component Specifications", Brown, D.E. and Rowland, R.U. - Vitro Corp. of America, Silver Spring, Md. Tech. Report No. 56 (Contract DA-36-034-ORD-1425) Feb. 25, 1954.

> A survey of 105 military specifications for electronic component parts and several electronic equipment specifications reveals serious inadequacies with respect to reliability in guided missile systems applications. Specified environmental tests for component parts are generally few in number, non-uniform or poorly integrated, and the specifications themselves suffer from non-uniform format. The report recommends that (1) the maximum capabilities of existing component parts be determined by testing to destruction under various environments, (2) a comparison be made of the part capabilities and the missile system requirements, (3) the Ordnance Corps work with the other services to promulgate a mutually agreeable higher level of environmental requirements for a group of component parts intended for use in these more stringent applications, (4) component parts be improved or developed as necessary to meet the missile requirements and to fulfill the supporting ground equipment operational needs, (5) the specifications be revised concurrently with the development of component parts to include the new environmental requirements, (6) the determining and listing of Qualified Products for each specification be accomplished as soon as possible. These Q.P.L's should be made more readily available to contractors.

ENVIRONMENTAL

"The Air-cooled Electronic Chassis", Mark, M. and Stephenson, M. - ASME paper 55A-55; ASME Annual Meeting, Nov. 13-18, 1955

"Heat Transfer in Miniaturized Electronic Equipment", Anon - NAVships 900,189; Bureau of Ships, Navy Dept., Washington 25, D.C. Feb. 1955.

"Guide Manual of Cooling Methods for Electronic Equipment", Anon - NAVships 900,190; Bureau of Ships, Navy Dept., Washington 25, D.C. - March 1955

"Questionnaire on Telemetering Environmental Requirements", E.P. Halpin, E.E.C. Member, Bendix Products Division - Missile Summary of E.E.C. 56-26

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"Application of Continuous Spectra Forcing Function to Vibration Analysis", Wimpey, J.T. (McDonnell Aircraft)- GMRWG Report No,5 - U.S. Navy Inter-Bureau Technical Committee, Washington, D.C. December 1955

> A method is presented of applying the continuous spectrum concept to vibration analysis of electronic components. In evaluating and defining this method the following work has been done (1) tentatively defined the nature of the missile vibration environment, e.g. random amplitude variations and white in frequency, (2) designed a suitable voltage generator to simulate this assumed environment, (3) converted a conventional vibration exciter to provide a uniform acceleration response, (4) provided networks to shape the forcing function in amplitude and/or frequency to match a known environment (5) designed a direct reading probability distribution meter to measure directly the statistical amplitude distribution of the forcing function, (6) designed an acceleration detector for calibrating the acceleration at discrete frequencies throughout the bandwidth of the forcing function, (7) established a method of evaluating the magnitude of the forcing function in terms of rms acceleration.

"On the Reliability of Networks", Weiss, George H.; Kleinerman, Meinhard, M. - Proceedings of National Electronics Conference Vol. 10, 1954

"Cooling Methods for Electronic Equipment in General", Robinson W., Beitler, S.R. - USAF Contract W33-038-AC-14987 Report #20, dated July 1948.

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"Components Reliability Program - Final Report", Anon - Bell Telephone Labs., Navy Dept., BuShips Contract NOBSR-52480 Index NE-111406, dated 15 July 1953

"Reliability in the General Military Specifications for Guided Missiles", Lusser, Robert - Publication of the Redstone Arsenal - 4 November 1952

"RCA Reliability Program and Long Range Objectives", Ryerson, C.M. - RCA Engineering Products Division - March 15, 1955

In this report highlights of the recent developments as seen by RCA in the field of Reliability were discussed.

"Some Reliability Aspects of Systems Design", Moskowitz, Fred and McLean, John - RADC Technical Note 55-4

"Reliability is Your Responsibility", Jurgen, Ronald K. - Electronic Equipment, January 1956

Present unacceptable level of electronic equipment is due to lack of maturity of product design and failure to evaluate the inherent reliability of design through realistic engineering tests and service and material evaluation, before major production is undertaken.

"Aspects of Electronic Equipment Reliability", Harris, Victor - Proceedings of the National Electronics Conference - 1952, Vol.B

The objective for improving operational reliability in shipboard electronic equipment should be to achieve low maintenance, failure-free equipment. To attempt to obtain reliability by incremental improvements is to work in the region of diminishing returns. Mechanical weaknesses in Navy electronic equipment, it is found are one of the most persistent and serious sources of unreliability. It is concluded that the traditional engineering task of adapting established materials, parts and techniques to new applications will provide the solution to a large part of the reliability problem.

"Component Part Reliability", Messner, Roy (Glenn L. Martin Co.) AIA/EEC Reliability Panel Meeting; Att (2); EEC 56-23 Dallas, Texas, 26-27 Jan.1956

Improved reliability in complex electronic equipments will result only with improvements in (I) Component Part Specifications to provide for improved reliability levels and (II) Methods of Estimating and Measuring Reliability. Under item I, the initial quality level for components must be tightened, design improvements must be made in

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equipments, processes and materials controls exercised by the parts manufacturer must be improved, failure rate data under typical end use conditions must be acquired, longterm quality requirements specifications must be improved, sampling plans which give consideration to both the producer and consumer risks must be adopted and variables sampling must be substituted for attribute sampling. Under item II, effort should be made to establish accelerated life testing in cases where the correlation between these accelerated tests and actual life under end use can be established, and increased effort should be placed on establishing failure rate data for the more commonly used component parts.

"Emphasize the Negative", Noble, Daniel, E. (Motorola Inc., Chicago, Ill.) - Proceedings - 1954 Electronic Components Symposium, Wash. D.C.

The reliability of a piece of equipment is complex and too much emphasis upon single-unit operational reliability in a particular case may actually reduce substantially the reliability overall "use factor". To determine reliability, human judgement, guided by a complete understanding of both the equipment systems operational requirements and the customer operational involvement. There is too great a gap between the design engineer and the man who must use the equipment. In order to minimize this gap, faults and failures developed in equipment after released by the manufacturer to field use, must be reported back to the manufacturer's designers. Routines must be established to permit modifications and corrections to be routed directly into the manufacturers' lines so that additional scheduled units will carry the improvements. Sectionalizing or sectional improvement is desirable to permit retrofitting for modernization and improvement without resorting to complete model-change approach.

"Sound Engineering - The Foundation of Equipment Reliability", Bridges, J. M. Director of Electronics, Office of the Assistant Secretary of Defense (Applications Engineering) - an address - Aberdeen Proving Ground - 5 Oct. 1955

The greatest cause of the present unacceptable level of reliability in military electronic material is the lack of maturity of product design and failure to evaluate the inherent reliability of design, through realistic engineering tests and service and material evaluation, before major production is undertaken.

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"Control and Power Supply Problems of Instrumented Satellites", Stublinger, Ernst - Redstone Arsenal, Huntsville, Ala. - IRE Transactions on Instrumentation - June 1956

Schemes for an attitude control system and for electric power supplies for unmanned satellites are presented. The attitude of the satellite with respect to the earth's center is controlled within 10 degrees by utilizing the shadowing effect of the earth on the isotropic cosmic radiation. Three sources for electric power described are: (1) converting the sun's radiating energy with a silicon junction photoelectric generator, (2) directing the sun's radiation toward a pile of thermocouples made of ZnSb and constantan, (3) using a radioactive isotope, strontium 90 and yttrium 90 as heating element for a pile of thermocouples.

"Proceedings of Symposium on Environmental Criteria in Guided Missiles", Fleck, Frank, A., Editor - Technical Memorandum No. 110, White Sands Proving Ground, Las Cruces, New Mexico, 20 December 1953 (SECRET)

"Proceedings of Symposium on Guided Missile Reliability", Pierce, J.J. and Moss L.Q., Editors - Report No. 233 Part I, Naval Ordnance Laboratory - Corona, Cal., October 26,27,28, 1954 (SECRET)

"Proceedings of Symposium on Guided Missile Reliability", Pierce, J.J. and Moss, L.Q., Editors - Report No. 233 Part II, Naval Ordnance Laboratory - Corona, Cal. , October 26, 27, 28, 1954 (SECRET)

HUMAN ENGINEERING OPERATIONS RESEARCH

"Human Engineering Guide for Equipment Designers", Woodson, Wesley E. - Univ. of California Press 1954

This guide is intended to aid the designer in making optimum decisions wherever human factors are involved in man-operated equipment, by providing a central source for information about the human operator, by pointing up the relative importance of variables which make a difference, and by indicating solutions for typical design problems.

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HUMAN ENGINEERING OPERATIONS RESEARCH

"Handbook of Human Engineering Data for Design Engineers", Anon Institute of Applied Experimental Psychology, Tufts College, Technical Report SDC 199-1-1, NAV Exos P-643 (Distributed by U.S. Dept. of Commerce, Office of Technical Services, Washington 25, D.C.) 12/1/1949

"Operational Analysis of a Field Support Program for a Complex Weapon System", Dresner, J., Shapero, A. - Presented at American Rocket Society Fall Meeting, Sept. 18-21, 1955, Los Angeles, California.

> It is the intent of this paper to introduce the subject of the field support of a complex weapon system and to formulate a conceptual model which can be used in developing and maintaining such a field support system. The paper contains, (1) a statement of the objectives and boundary conditions of the field support system, (2) the textual and graphical presentation of the field support centered conceptual model of a missile weapon system, (3) a discussion of the development of a field support system using the model.

MATERIALS

"Proposed Guide for the Preparation of Test Procedures for Evaluating the Thermal Stability of Insulating Materials", Dexter, J.F. et al - AIEE Winter General Meeting CP-56-329 Feb. 3, 1956

"Radiation Effects on Dielectric Materials", Naval Research Lab., - Papers submitted at NRL conference on the effects of radiation on dielectric materials, December 1954, Office of Technical Services, U.S. Dept. of Commerce, Wash. 25 D.C. $4.25 Request #PR11863

"Effects of High Humidity on Dielectric Properties of Casting Resins", Graves, H.K. and Pissino, M.A. - Electrical Manufacturing, April 1956, pp. 89 - 93.

> Humidity tests conducted on 16 different casting resins show that except for two of the materials the insulation resistance drops from above 10^8 megohms to as low as 0.02 megohms for soaking periods of as much as 140 days. At the same time the dissipation factor at 60 cps increase from less than 0.008 to more than 100 in some cases. For most materials the capacity also increases with humidity, in some cases more than 100 times. In general the data indicate the epoxies are far more resistant to moisture under the conditions of the test than are the polyesters.

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MATERIALS

"Metal Whiskers - A Factor in Design", Arnold, S.M. (Bell Telephone Labs., Inc., Murray Hill, N.J.) - Proceedings 1954 Electronic Components Symposium, Wash. D.C.

Metal whiskers are tiny filaments which have been found projecting from the surfaces of certain metals. They are metallic in appearance and highly reflecting. They are generally 40-80 millionths of an inch in diameter. Many have been found longer than 3/8". While possessing high intrinsic strength, they are easily moved by a current of air, and may be dislodged by mechanical shock. Since they are metallic they have low electrical resistance. When a projecting whisker makes contact between two circuit elements it will reduce the resistance between them to 300 ohms or less. An applied voltage of 10 volts or more is sufficient to burn off the whiskers. X-ray patterns indicate that whiskers are metal crystals rather than corrosion products. Whiskers have been found to grow on several metals and alloys. Various conditions of temperature, relative humidity pressure and various coatings and plating have not shown any decisive role of the control of whiskers.

Under such circumstances the possibility of whisker growth must be considered when designing equipment which is electrically sensitive and whose premature operation or failure to operate could result in a serious situation.

"Magnet Wire Performance in Product Life Tests", Balko, R.L. (Associate member AIEE) (G.E. Co. Fort Wayne, Ind.) - AIEE Transaction paper - No. 56-152

Measured performance of magnet wire in product life tests provides design data for the proper use of magnet wire in an insulation system. To direct the application of a magnet wire, evaluation methods must (1) establish mechanical and thermal limits. (2) determine compatibility with varnish treatments, (3) compatibility in a complete insulation system. Mechanical and thermal limits of magnet wire alone can be established by the use of several screening test methods, each measuring a particular property. Most motor applications require windings to be bonded firmly together and to the ground insulation. Performance of magnet wire in an insulation system is dependent upon the ability of a varnish to have good adhersion, provide an element of flexibility and be chemically compatible with the wire it is impregnating. Factors of normal fabrication, realism in test and economics in preparation, substantiate why the motor test is considered the best known tool to measure performance of magnet wire in insulation system of small motors.

MATERIALS

"Evaluation of Insulating Materials in Simple Combination", Mathes, K.N. (Member AIEE) - Paper presented at the AIEE Winter General Meeting, New York, N.Y. Feb. 3, 1956

Two different approaches are often taken in the evaluation of insulating materials. (1) Evaluation of individual Insulating Materials (2) Evaluation of Complete Insulation Systems for Specific Types of Equipment. It is believed that evaluation of materials in simple combination can provide evaluation which is significant to the use of insulating materials.

"Thermal Evaluation of Enameled Magnet Wire", Dexter, J.F. (Member AIEE)(Dow Corning Corp., Midland, Mich.) - AIEE Transaction Paper - No. 56-153

The thermal life of an electrical insulating system made up of magnet wire coated with a modified-silicone enamel and other silicone components has been evaluated by three different test methods; (1) Test Procedure for trial use for evaluation of the thermal stability of enameled magnet wire, (2) Test Code for evaluation of systems iof insulating materials for random-wound electric machinery, Part I, Motorettes, (3) Test Code for evaluation of systems of insulating materials for random-wound electric machinery, Part II, Motor tests.

The thermal life values obtained on the insulation system by three test methods show excellent correlation. Data presented show that the modified-silicone enameled wire together with silicone components provide an insulation system in random-wound electric machines qualifying for operation at class H temperatures.

"Guiding Principles in the thermal Evaluation of Electrical Insulation", Berberick, L.J. (Fellow AIEE); Dakin, T.W. (Assoc. member AIEE) Westinghouse Electric Corp., East Pittsburgh, Pa. AIEE Transaction Paper - No. 56-248, 1955

The rating of electrical insulating materials for use at various temperatures for an adequate service life requires a knowledge of the manner in which the insulation deteriorates in service, and the rate of this deterioration. This paper summarizes the various mechanisms of insulation deterioration. Accelerated aging procedures should be designed to simulate as closely as possible the environmental conditions in the apparatus. The criterion of failure should be based upon the function which the material or system of materials has to perform.

Accelerated aging tests should be carried out at a minimum of three temperatures to establish that the life values so obtained can be extrapolated to normal hot spot temperatures. Accuracy in this data should be determined by statistical methods.

"The Effect of Reactor Irradiation on Electrical Insulation", Pigg, J.C.; Bopp, C.D. ; Sisman, O.; Robinson, C.C. - Communications and Electronics, Jan. 1956 - No. 22.

The presence of a radiation field subjects the insulations of a circuit to environmental conditions which both accelerate the normal processes of deterioration and introduce new characteristics to the insulation behavior. The resistance of an insulation under irradiation drops to some value which is a function of the flux level and maintains this level as irradiation proceeds. Eventually the insulation resistance drops again. This final drop can be designated the breakdown of the insulation. The change in insulation resistance in the presence of a field causes ionization which provides charges. These charge carriers give to the insulation properties similar to a semiconductor and result in the nonohmic resistance as well as photovoltages. These photovoltages change in sign and magnitude depending on the sign of the carrier. Voltages as high as 200 v have been observed.

"The Effects of High-Energy Gamma Radiation on Dielectric Solids", Klein, Philip H.; Clifford - Communications and Electronics Jan.1956 - No. 22

This paper discusses (1) the nature of nuclear radiations, (2) the locations and approximate intensities with which they exist in the vicinity of nuclear reactors (3) the reaction processes of these radiations with matter, (4) experimental techniques, (5) results of tests made at the Knolls Atomic Power Lab.

"Heat-Resistant Insulation Systems for Motors", Herman, C. J.; Mathes, K.N. - Communication and Electronics - November 1955 No. 21

Allsanex wire has been shown by four different types of temperature-aging tests to process approximately a 40C superiority in thermal stability as compared to Formex wire when used in combination with several types of varnish systems. Evidence is presented to emphasize that the temperature capability of insulating materials may be determined by test rather than by definition alone. The various types of tests used emphasize different characteristics of insulation systems and give a greater understanding of the changes that occur during again than would a single type of test.

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"Materials in Advanced Electronics Design", Middleton, A.E. (P.R. Mallory and Co. Inc., Indianapolis, Ind.) - Electrical Manufacturing - May 1956

The interrelation of materials, components, circuit techniques and ultimate product design is analyzed and graphically shown in this discussion.

"Copper-Clad Fluorcarbon Printed Wiring Boards", Allen, Louis B., Stein, Sydney, J. (International Resistance Co., Phila., Pa.) Electrical Manufacturing - May 1956

Special surface treatment provides effectively bonded copper and polychlorotrifluordethylene for printed circuit use. Same bonding technique can be used in component fabrication, such as hermetic seals. Inherent characteristics of the virgin fluorocarbon polymer are retained since no reinforcing material, nor adhesive, is needed.

THEORY

"Reliability of Guided Missiles", Lusser, Robert (Redstone Arsenal) - American Society for Quality Control, National Convention Transactions, 1955, pp. 691-704

This is a representation of an earlier paper by Lusser in which he contends that reliability in a guided missile is a great deal more stringent and serious than it is in aircraft, because a single failure of any component will cause loss of the missile, while in an aircraft the pilot will parallel for the lost component, or get along without the function until the failure can be repaired. He then develops the basic reliability mathematics and the exponential failure law and finally ties in his "test-to-failure" concept.

"Principles and Concepts of Reliability for Electronic Equipment and Systems". Luebbert, Capt. W.F. (USA) - Stanford Electronics Research Laboratory Technical Reports Nos. 90 and 91, 1956.

"Handbook of Preferred Circuits", Anon - U.S. National Bureau of Standards

"Reliability Factors for Ground Electronic Equipment", Henney, Keith, Editor - McGraw Hill Book Co., New York 1956.

"Symposium on Electronics Maintenance", Anon - U.S. Dept. of Defense, 1955

"A Statistical Reliability Theory", Drenick, R.F. (RCA, Camden, N.J.) Report EM-4221 - April 5, 1956

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THEORY

"Numerical Reliability", Ryerson, C.M. (Reliability Administrator, RCA, Camden, N.J.) - Proceedings - Second National Symposium on Quality Control and Reliability in Electronics - Washington, D.C. - Jan. 9-10, 1956

> This paper reviews methods for numerical assessment and proposes that they be discussed, modified and established as national standards. The goals of numerical assessment are: (1) to establish a system for defining and comparing the reliability of equipments at various stages of their design and use (2) to explain the relative importance of various design objectives (3) to provide a numerical evaluation of failure or success in field operations, and (4) to provide a procedure for compiling and coding related reliability information so that it can be handled in large quantities by automatic accounting machines.

QUALITY CONTROL AND STATISTICS

"A Survey of the Current Status of the Electronic Reliability Problem", Carhart, R.R. - U.S. Air Force, Project Rand, Rand Corp., Research Memorandum #RM-1131, dated 14 August 1953

"Facts from Figures", Moroney, J. J. - Penguin Books Ltd., Harmondsworth, Middlesex, England.

"The Definition of Terms of Interest in the Study of Reliability", Knight, C.R.; Jervis, E.R.; Herd, G.R. (Aeronautical Radio, Inc., Washington, D.C.) - IRE Transactions on Reliability and Quality Control - April 1955.

> Reliability is studied in terms of discrete Variables and continuous variables and their combined effects, with consideration of the interdependence of components. The concept of dependence is developed to facilitate measurement of the effectiveness with which components are incorporated into a system. Weighting functions are proposed to give mathematical expression to user opinion versus equipment performance characteristics.

"Electronic Data Processing", Stephenson, J.D. (Hughes Aircraft Co., Culver City, California) - American Society for Quality Control - National Convention Transactions, 1955, pp 141

"A Quality Control System for Job Shop Electronic Equip. Manufacture", Berkenhamp, Fred J. (General Electric Co., Schenectady) American Society for Quality Control - National Convention Transactions, 1955, pp. 641.

QUALITY CONTROL AND STATISTICS

"Applications of Statistical Methods in Evaluating Performance of Electronic Equipment", Madison, Ralph L. (ARINC, Washington) American Society for Quality Control - National Convention Transactions - 1955 - pp 209

"Selective Assembly", Murphy, R.B. (Bell Telephone Lbs., New York) - American Society for Quality Control - National Convention Transactions - 1955 - pp 409

"Redesigning for Production", Romig, Harry, G. (International Telemeter Corp., Los Angeles) - American Society for Quality Control, - National Convention Transactions - 1955 - pp 521

"A Statistical Method for Predicting Insulation Life From Experimental Data", Horton, W.H. (Non-Member AIEE)(Westinghouse Electric Corp., East Pittsburgh, Pa.) - AIEE Transactions Paper No. 56-177

The technique of evaluating the suitability of an insulation system is known as "regression" analysis. This method is concerned with the study of the relationship between two or more variables, such as insulation life and operating condition. The regression analysis for these examples would be a study of y, insulation life, as a function of x, operating condition. $Y = a + bx$. The life of an insulation system would be approximated by

$$\text{insulation life} \sim \frac{1}{\text{reaction rate}} = A\, e^{B/T}$$

A,B are constants.
T is abs.temp.

$\log y = \log A + B/T$ is now in the convenient form of

$Y = a + bx \qquad \log y = Y,\ \log A = a,\ B = b,\ \frac{1}{T} = x$

Insulation life, after a logarithmic transformation, and operating temperature was found to follow the linear form. In order to use this technique three assumptions must be fulfilled: (1) the designation of the dependent and independent variable usually is from a suspected cause and effect relationship, with the independent variable as the cause, and the dependent variable as the effect, (2) the variation in, or variation of, the dependent variable must be homogeneous for different values of the independent variable, (3) if confidence limits are used, the variance of the dependent variable must be homogeneous and the dependent variable must be assumed to be distributed normally or approximately so.

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"Connector Contact Improvement Through Quality Control", Cannon, James;Maston, Frederick (Cannon Electric Co., L.A., Cal.) - Proceedings - Second National Symposium On Quality Control and Reliability in Electronics - Washington, D.C. - Jan. 9-10, 1956

> To increase the reliability of any component, it is necessary to think in terms of statistical distributions of important physical properties. From field reports of failure and laboratory test results, we must first select those properties which most frequently cause trouble. It is then necessary to determine whether poor performance is due to lack of process control to keep the product within specified tolerance limits, or whether the design itself is inadequate for an end-use application. In either case, the use of the statistical approach to problem solution offers a positive method of obtaining known levels of reliability.

"Life Factors Affecting Acceptance Procedures", Acheson, Marcus A. (Consulting Staff Engineer - Sylvania Electric Products, Inc.) Proceedings - Second National Symposium on Quality Control and Reliability in Electronics - Washington, D.C. - Jan. 9-10, 1956

Increasing electronics complexity requires extended development of present statistical acceptance procedures. Current and required developmental procedures are distinguished and explored for further developmental guidance.

"Statistical Technique for Reducing Experiment Time in Reliability Studies" Sobel, M. Bell System Technical Journal 35 - Jan. 1956

"Statistical Methods in Research and Production" - Davies, O.L. Landon 1954

"Design and Analysis of Industrial Experiments" - Davies, O.L. et al Landon 1954

"Monte Carlo Methods" A.S. Householder ed. - National Bureau of Standards, Applied Math Series 12 - Washington, D.C. 1951

"Techniques of Statistical Analysis", Eisenhart, C., Hastay,M.W. and Wallis, A.W. New York 1947

"Sequential Analysis" Wald,A. New York 1947

"Statistical Theory with Engineering Applications" - Hald, A. New York 1952

"An Introduction to Probability Theory and its Application" Feller, W. - New York 1950.

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QUALITY CONTROL AND STATISTICS

"An Introduction to Stochastic Processes" - Bartlett, M.S. Cambridge 1952.

"Proceedings of the Symposium on Monte Carlo Methods" Gainesville (1954) (In publication)

"Life Testing" - Epstien, B. and Sobel, M. - J.Amer. Stat. Assn. 46.1953

"An Analysus of Sonc Failure Data" - Davis, D.J. - J. Amer. Stat. Assn. 45-1952

SYSTEM EVALUATION MEASUREMENT AND PREDICTION

"Reliability Theory and Vital Engineering Interpretations", Wuerffel, H.L. (RCA, Camden, N.J.) - Reprint of a technical paper presented May 3, 1956 - 1956 Electronic Components Symposium, Dept. of Interior Auditorium - Washington, D.C.

Two basic concepts concerning the numerical reliability prediction for electronic equipments and systems are (1) that equipments fail by performance degradation, (2) that in addition to performance degradation failures, equipments become inoperative because of catastrophic failures of the components

"A Systematic Plan for Predicting Equipment Reliability", Connor, John A. - Reprint of a technical paper presented May 3, 1956 1956 Electronic Components Symposium, Dept. of Interior Auditorium - Washington, D.C.

This paper outlines the objectives, methods and significance of an engineering program for the prediction of Reliability in complex electronic systems, through the consideration of significant component and component application factors.

"Designing for Reliability", Taylor, N.H. - Lincoln Laboratory - MIT Industrial Liaison Office - Technical Report No. 102, June 13, 1956

There are three main phases in a design project: (1) to consider each individual component to be used in the system and to critically analyze its capabilities and limitation, (2) to determine the applications of these components that tend to take advantage of the best capabilities of these components and avoid their worst limitations, (3) the actual electronic circuit design, based on the component analyses and applications notes derived earlier and predicted on the achievement of high reliability. This method provides reasonable component tolerences and adequate safety margins, and incorporates marginal checking throughout the design process.

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"Reliability Concepts and Methods for the Improvement and Evaluation of Guided Missile Systems", Duffett, James R. - Paper delivered at the American Rocket Society - 23 Sept, 1954 El Paso, Texas

"Manual of Temperature Measuring Techniques, Units, and Terminology for Electronic Equipment", Anon - Dept. of Navy - Bureau of Ships - Navships 900,187, 15 April 1954

Certain electronic and electronic heat transfer terminology is defined in this manual in order to provide a mutual basis of understanding and to avoid confusion. Temperature measuring techniques are presented to assist in the testing and design of reliable miniaturized electronic equipment. Also a hybrid system of heat transfer units is recommended.

"Designing Reliability into Electronic Circuits", Benner, A.H., Meredith, B. - RCA General Engineering Development Section 591 - EM4208, Oct. 27, 1954

This analysis yields the survival probability of an equipmemt or it may be formulated to give the individual component specifications. A linear variations analysis is applied to a mathematical representation of the transfer function of a circuit or system. The overall system specifications are then used to determine a threshold of failure on the error analysis. It is assumed that the item-to-item scatter of the value of components, tube characteristics, etc., is Gaussian, and the means and variances are determined as a function of time and environment.

"Statistical Analysis of Equipment Reliability", Meltzer, Sanford A. (RCA) - RCA Engineering Products Division - EM4194 - June 29, 1955

The object of this report was (a) to describe the exact and the approximate methods for computing the survival probabilities of a circuit from statistical descriptions of the behavior of components (b) to compare these methods as to accuracy and complexity with the approximate method described in EM 4208 (c) to discuss certain special problems, such as correlation among performance parameters. Two methods for the determination of the reliability of an electronic equipment were formulated. The exact, or "change of variable" method, and an approximation procedure.

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"The Stress-Step Method of Obtaining Short-Term Life Ratings on Electronic Components", Jerencsik, A.P.; Sackett, W.R. Jr. - (Battelle Memorial Institute) - Proceedings of the National Electronics Conference - 1952 Vol. 8

Some military applications of electronic components require operation at high ambient temperatures and loads. If this is done, the penalty of a shorter life must be paid. Before such applications can be made on a sound basis, short-term life ratings as a function of temperature, load and altitude must be obtained. Several methods of obtaining such methods are described. A step test to obtain the temperature or load at which the determination of the component just becomes important in a given lifetime is recommended. Variability from component to component appears relatively low with this approach. Initial evaluations of the method on composition and carbon-film resistors show that valid data are obtained by this method.

"Electronic Failure Prediction", Muncy, J.H. (National Bureau of Standards, Wash. D.C.) - Proceedings of the National Electronics Conference - 1952 Vol. 8

Electronic failure prediction is defined as detection of incipient failures and its use is outlined in the reliability program. The application of this technique to a receiver is discussed and the method and results of a laboratory evaluation program are presented. The conclusion is drawn that failure prediction can contribute to dependability when extremely reliable performance is required.

"A Statistical Method of Specification, Testing and Evaluation of Missile Systems" Althans, E.J. and Morrison, S.C. and Tate, W.R. - Guided Missile Research and Development Division Hughes Aircraft Co. Tech. Memo 368 (Contracts AF33(038)28634 and AF33(600)24231 (AD-51252)

"Techniques for Reliability Measurement and Prediction Based on Field Failure Data", Anon - Summary Report - Electronic Equipment Reliability Program - Vitro Labs., Silver Springs, Md. Technical Report #80, 10 Oct. 1955

This is a report of work done so far on techniques for measuring and evaluating electronic equipment reliability on the basis of statistical quantities of failure date, and for predicting it on the basis of design guide lines.

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"Evaluation of Complex Systems in Guided Missiles", Davis, R.G. and Fullenwider - National Bureau of Standards Report No. 1237 (AD-51241)

"Evaluation of Reliability in Guided Missile Systems", Sams, G.R. (US NOL, Corona, Cal.) - American Society for Quality Control, National Convention Transactions, 1955, pp 643 - 652.

Sams points out that to get a true feeling for the reliability of a future missile, both objectivity and subject matter competence are needed. The design-developer has the subject matter competence but it is questionable that he can be completely objective about his creation. The independent evaluator may be completely objective but less completely competent, technically. This suggests a coordinated program of test and evaluation conducted by an independent evaluator with assistance from the designer. The test and evaluation program should be initiated at the design and development phase and carried on through the production and operational phases. All test methodology and terminology should be standardized for all phases of the program so that the data obtained for the various phases can be correlated.

"The Systems Approach to Reliability", Carhart, Richard R. (Lockheed Aircraft Corp. Missile Systems Division, Van Nuys, Cal.) - Proceedings Second National Symposium on Quality Control and Reliability on Electronics - Wash. D.C. - Jan. 9-10, 1956

The system approach to reliability is discussed. The role of sub-system reliability testing as a bridge between early component work and final system evaluation is considered. The technical need for system testing is established by examining the basic concepts of system and component reliability and noting the importance of component interactions. Finally, the advantages and economies of subsystems testing are noted.

"What Guided Missiles do to Components", Stine, H.A. (Capehart-Farnsworth Co., Fort Wayne, Ind.) - Proceedings 1954 Electronic Components Symposium, Wash. D.C.

The initial shock of a fired missile often reaches 50 - 60 g's or more. During flight the estimated vibration is estimated at 8 - 10 g's with frequencies up to 500 cycles. Recent work done indicates vibration frequencies up to 2000 cycles. In addition to vibratory forces there is the problem of limited available space. This creates a demand for miniaturization. Miniaturization of components accentuates the problem of dissipating heat generated. Transistors offer a promising approach to this problem

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However, due to transistor limitations, tubes will continue to be used. Faults in tubes are of such nature that the tube manufacturer can eliminate them and strive for better tubes. Another major source of trouble, besides tubes, in missiles, are large numbers of relays. By nature, relays are susceptible to vibration, shock, contamination. Relay design must compromise between the operating force resulting from magnetic flux and the mechanical restoring force. It is quite difficult to design metal chassis with natural resonant points outside the danger spectrum. A newer method of approach to this problem is the use of "printed circuits" or "printed wiring". Printed wiring or printed circuitry can be roughly classified as the silk-screen process and the photo-etching method. The major shortcoming of either process is that component parts designed for this technique are not available in the missile field. Component parts suitable for commercial use will not pass specifications in the missile field.

"Prediction of Missile Reliability", Kirby, M.J., Powell, H.R. - Sperry Engineering Review - July, August 1955.

The method is described for predicting reliability by testing missile components by increasing the environment until failure occurs and expressing their strengths by curves of probability of failure occurs and expressing their strengths by curves of probability of failure vs. intensity. These are compared with curves of probability of occurrence of environment vs. intensity. This procedure differs from the present method in that it does not take time into account as a basic part of all failures. The tests to failure in the present method are run at constant intensity and increasing duration in order to preserve the order in which the failures occur in normal use.

"Prediction of Electronic Equipment Reliability", Harris, V., Tall, M.M. - Electrical Engineering - November 1955.

Analysis confirms that reliability depends strongly upon the severity of the components application. The analysis was concerned primarily with shipboard equipment. Additional design factors may require consideration under more or less severe requirements. The component failure rates may be different under other environmental conditions.

"Components Evaluation for Airborne Systems Performance", Kleinhofer, B.A. (North American Aviation, Inc., Downey, Cal.) - Proceedings Second National Symposium on Quality Control and Reliability in Electronics - Wash. D.C. - Jan. 9-10, 1956

Components evaluation for the selection, application and standardization of components used in airborne electronic systems is discussed with illustrations of current component problems.

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"The Effect Upon Calculated Reliability of Errors in Field Malfunction Data", Smith, Mark H. (Sperry Gyroscope Co., Great Neck, L.I., New York) - Proceedings Second National Symposium on Quality Control and Reliability in Electronics Washington, D.C. - Jan 9-10, 1956

Analysis and examples showing that large errors in data may cause only very small errors in reliability. For a high reliability percentage, even substantial data errors produce much smaller errors in reliability. It is improper to discount reliability calculations because of inaccuracies in the basic data, due to its exponential characteristic, the reliability formula dampens or smooths out the data error and the degree to which it does this increases rapidly with high values of reliability.

A given error in data (if less than 50%) will cause a less than equal error in reliability for all reliabilities higher than approximately 50%.

"A Progress Report on Reliability Measurement and Prediction", Harris, Victor; Tall, Max. M. (Vitro Labs., Silver Springs, Md.) Proceedings Second National Symposium on Quality Control and Reliability in Electronics - Washington, D.C. - Jan. 9-10, 1956

Vitro Laboratories, under contract with the Bureau of Ships, is working on the development of a method for measuring electronic equipment reliability and the rough guide lines by which reliability can be predicted as a function of design factors which can be seen as early as the "drawing board" stage of equipment development. An initial test of predicted guide lines was performed on two equipment models. Although results of this test are encouraging they are rather limited and statistical inferences should not be drawn. They show that the predictions are of the proper order of magnitude.

"Statistical Approach to R. and D. Problems", Brickley, R.L.; Horton, W.H. (Westinghouse Electric Corp., East Pittsburgh, Pa.) Electrical Manufacturing - May 1956.

Inherent in the statistical approach through the techniques of experimental design, is the ability to evaluate the effects and interactions (joint effects) of several variables with a minimum number of test combinations. The efficiency of the statistical approach is generally realized in two ways (1) as many as possible of the variables whose effects are to be evaluated are included in the same experiment and (2) estimates of these effects can be obtained with a reduced number of observations.

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