THE PROBLEM OF PRODUCIBILITY

4 January 1955

CONTENTS

Page

INTRODUCTION--Brigadier General Urban Niblo, USA, Deputy Commandant, ICAF..... 1

SPEAKER--Mr. Theodore A. Smith, Vice President and General Manager, Engineering Products Division, Radio Corporation of America..... 1

GENERAL DISCUSSION..... 34

NOTICE: This is a copy of material presented to the resident students at the Industrial College of the Armed Forces. It is furnished for official use only in connection with studies now being performed by the user. It is not for general publication. It may not be released to other persons, quoted or extracted for publication or otherwise copied or distributed without specific permission from the author and the Commandant, ICAF, in each case.

Publication No. L55-73

INDUSTRIAL COLLEGE OF THE ARMED FORCES

Washington, D. C.

Mr. Theodore A. Smith, Vice President and General Manager, Engineering Products Division, Radio Corporation of America, was born in Brooklyn, New York, 17 February 1905. He received his degree in mechanical engineering from Stevens Institute of Technology in 1925, and immediately joined the staff of RCA's technical and testing laboratory at Cortlandt Park, New York. Three years later he was placed in charge of television development work at Cortlandt Park and became one of the pioneers of television development. He has advanced steadily through technical, commercial, and administrative positions since his start with RCA more than 27 years ago. In 1930 Mr. Smith entered the commercial engineering field as a district manager for RCA transmission equipment, with headquarters in New York. He was assigned to the Camden, New Jersey, headquarters of RCA Victor Division in 1938 and progressed through key posts in the fields of product coordination for commercial and military equipment, and military development projects to the position of general sales manager of the Engineering Products Department, RCA's organization concerned with the design and production of military and commercial electronic equipment. He was made assistant manager of this department in January 1951 and was elected to be vice president in June 1953. Mr. Smith is a member of the Institute of Radio Engineers, the American Society of Naval Engineers, the Armed Forces Communications Association, and is Chairman of the Government Equipment Section of the Radio-Electronic-Television Manufacturers Association.

THE PROBLEM OF PRODUCIBILITY

4 January 1955

GENERAL NIBLO: Admiral Hague, ladies, and gentlemen: Yesterday you heard about the value of a good military-industry relationship. In commercial practice the essential relationship is sometimes called the customer-dealer-industry team, wherein the distributor and the dealer act as the "go between." They must represent the interest of the manufacturer by selling more products. They must also represent the interest of their customers by keeping them satisfied, also by transmitting to the manufacturer recommendations for essential improvements that the customers want incorporated in the firm's future manufactured goods.

We must incorporate this customer-dealer-industry relationship within our military-industry team if we are to achieve success in combat with the least difficulty to our economy. Although our technical services, our air materiel personnel, and our Navy bureaus have a monopoly within their respective fields, and hence are in competition, they must still act as go-betweens. They must represent both our using troops and commercial industry.

Producibility of military equipment is a positive problem of commercial industry. On the other hand the practicability of its use--the ease of maintenance and the ease of servicing and the reliability of that equipment during combat operations--is a definite problem of our using troops. As potential future wholesale productive producer logisticians, you must strive to perfect the relationship between our using troops and commercial industry. In other words you must strive to incorporate within our military-industry team that full concept of customer-dealer-industry relationship if you are to achieve economic mobilization.

We are very fortunate this morning in having with us Mr. Theodore A. Smith, Vice President and General Manager of the Engineering Products Division of the Radio Corporation of America. He will discuss "The Problem of Producibility" of military equipment.

Mr. Smith, it is a pleasure to welcome you back to our faculty of guest speakers and to present you to this year's class of the Industrial College.

MR. SMITH: Admiral Hague, General Niblo, gentlemen: It is both a pleasure and a compliment to have the opportunity to discuss with you the challenging subject of producibility of military equipment. The producibility of military equipment forms the core of the relationship between industry and the military which is so vital for our national defense. During World Wars I and II, it was demonstrated beyond all doubt that a strong, well-equipped American military force, backed up by the tremendous resources of our industrial capacity, could not be defeated. The combination of industry and the military met and solved many problems, but many production problems still remain to be solved. It is my purpose today to review some of these problems for our mutual benefit.

In many periods of the past, military weapons and devices remained static for long periods of time. But today, our comprehensive military plan requires that equipment be of the latest type, perform new functions, and have advantages over that possessed by a potential enemy. Of course, it must be available when needed--in sufficient quantities--it must be reliable, and of reasonable cost. Herein lie the basic problems of producibility.

Our military needs are ever changing toward greater performance and greater complexity. What about industry's ability to produce such high-performance equipment? Industry, does its best job when it produces long runs of completely designed and tested items of familiar types. Between these two concepts--the new, the unusual, the better equipment needed by the military, and the older, the known, the established, with which industry is familiar--lies the area of most of our difficulty.

As the military contracts with industry for equipment, the number of any one item may be only a handful, or it may be many thousands. The equipment may be very simple, in which case there is little problem, or it may be extremely complex, demanding the highest talents of our scientists and engineers, compounded with the ablest skills of our best production people. The equipment may be a standard item, in which case production is merely routine, or it may be a newly designed product.

Most problems of producibility are in this latter area, where the fast-moving demands of modern technology result in increasingly complicated gear and in increasingly stringent specifications for producing it. It is in this field, where engineering research and development are "pushing the art," that the military specifications are typically demanding

more than was ever heretofore accomplished on the factory floor. But there is an even further step where science is unfolding entirely new principles which demand for their utilization the development of brand new ideas, new techniques, and new methods.

In order to speak to you of matters within my own knowledge and experience, I must talk on the subject of producibility with reference to electronic equipment problems. This area is certainly one which should stimulate some interesting discussion, because there have been electronic production problems.

The Comptroller of the Air Materiel Command, General P. W. Smith, said in a recent speech, "In the field of jet engines, for instance, and electronic equipment--the heart and soul of our new planes--we are in trouble."

He went on to point out:

> "That is understandable in view of the extreme complexity and the specialized requirements for this type of equipment. . . . The fact is that we have some magnificent designs, but in too many instances, we cannot produce them with the functional quality we need, at a price within our budget, in effective quantity, on time."

Now, General Smith's comments refer specifically to the factors of time, cost, and quality, or reliability. These three factors are the keys to the problem of producibility of electronic equipment.

I should like to talk to you particularly about these problems of time, cost, and reliability in relation to the producibility of electronic equipment. While I refer particularly to electronics, by extension, many of the principles apply to any new, rapidly advancing technical field.

Let us talk for a minute about performance of equipment. Please note particularly that General Smith made no adverse reference to the performance of equipment. Those who have pointed up the problems of electronics have never made much of an issue of the ability of the gear to do things which no one guessed would be possible only a few years ago. We can design radar with superaccuracy. We can think up navigational devices which will locate a needle in a haystack. We can build a model of a computer which will juggle dozens of variable quantities

and, in four microseconds, tell you how many cosmic rays fell on the Pentagon yesterday.

It is a fact that the technical accomplishments of electronics are taken pretty much for granted. No one is complaining that the things which we need to do cannot be done. As manufacturers, we face tighter and tighter technical specifications and more demanding requirements. If fire-control systems for rockets are needed, our engineers design them. If a guidance system for a missile is asked of us, we take it in our stride. We no sooner have one design on the drawing board than another is in the development stage.

This is the order of the day. It is the nature of the cold war to demand the greatest possible performance from our equipment so as to be ready at any instant with superior weapons and operational systems. It is a requirement that we shall never be satisfied with what we have but constantly be in search for something which will add more performance features. It is undoubtedly vital for us to do so, lest our potential enemies contrive weapons which will outperform and outdo us. Certainly no war can be fought with the last war's weapons.

The pace of this technical race against time tends to leave behind the matter of producing quantities of devices. It may be advantageous to use practical realism in evaluating the need for new features in order to reduce producibility problems. In a rapidly developing field such as electronics, where tomorrow we will use a tube we only dreamed of today, the problems of producibility are very different from those in a stabilized field where techniques are known and all basic problems have been solved.

I would like to talk for a moment on the subject of complexity. The initial consequence of rapid development and pushing back of the frontiers of knowledge is complexity. Pascal, the philosopher, once wrote, "I have made this letter rather long only because I have not had time to make it shorter." There has not been time, for the most part, to simplify our designs, so we must do with complex ones. The normal consequence of attaining an objective with some difficulty is a complex design. If we can continue to work on the design, we can take much of the complexity out of it.

Let me give you an example of a commercial situation. The first experimental models of compatible color television receivers we built

in 1949 had 108 tubes. Our first commercial model, which was produced in 1954, contained 37 tubes. In 1955 we will put into production sets with only 28 tubes. Naturally, the 1955 model will be easier to produce and much less expensive than the original one. But we stuck with the problem. Having developed a color set, we worked toward simplification and cost reduction. This is the usual process in commercial development. Competition forces every manufacturer to follow step in attempting to simplify and cut costs. But the motives of military development are not the same as the commercial motives. If improved accuracy will increase the probability of fire control, we must constantly strive for greater accuracy rather than for simpler equipment. Hence we are not always able to "stay with" military design and take the complexity out of it.

We are faced with several other goals in military designing which lead us toward complexity. To carry a greater payload, we must eliminate weight and make our equipment smaller and smaller. At the demand for greater and greater speed, we must substitute electronics for a slow-acting human brain. We must compensate for lack of trained operating personnel by making our equipment self-operating. Miniaturized, automatic, and self-operating equipment can be designed, but the consequence is apt to be increased complexity.

There is one other factor which influences the design of our equipment. It is that we have exhausted the variations of simple designs. Until we have discovered and made practical new principles for achieving the desired high performance, we are stuck with complications. As an example of this kind of thing, consider the steamship. If we were obliged to construct modern ships using paddle wheels for propulsion, what problems we would face. The use of screw propellers simplified a number of ship-design problems. Here, a new principle made unnecessary the complex functions of an older method.

There are gradually coming into being new principles of electronics which may result in less complexity. Magnetic amplifiers and transistors are examples. When they can be applied, they are useful in simplifying some of our systems, particularly from a power-supply standpoint.

However, complexity, per se, is not necessarily an overpowering problem. A good many highly complex electronic circuits are in general use which can be easily supplied commercially and are extremely reliable.

When you watch a picture originating in a studio in New York on a television set here in Washington, you are observing the result of some 700 vacuum tubes operating in unison, not counting those in your own set. If one of these many tubes should fail during the broadcast, the picture, the sound, or both, would be interrupted at the Washington station and the network would be obliged to refund several hundred dollars to the advertiser. For important network broadcasts, a large number of broadcasting stations are interconnected and the failure of one tube could affect reception in numerous areas. Yet failure seldom occurs; witness the fact that television shows are commercially feasible and make money. Further, the equipment to do the job is available in quantity and is not particularly difficult to keep in adjustment.

It is, of course, an obvious fact that, as the number of circuit elements in a piece of apparatus increases, the cost will go up, the problems of producibility will be augmented, and the statistical probability of failure will become much greater than in a piece of equipment having a smaller number of parts of the same kind. Yet the apparatus with the greater number of parts may still be quite satisfactory if it has been fully tested over a long period of time.

The fear of complexity must be tinctured with the element of reality. A 22-tube TV set of today is cheaper, easier to make, and more reliable than a 10-tube radio of 1930. An automobile of today with automatic transmission is cheaper, can be built more rapidly, and is of a higher order of reliability than many relatively simple 1910 models.

We have learned to make better designs and better components. We have produced cars for a good many years. Seldom does a military supplier make the same kind of article for a long time. In the instance of military equipment, complexity can become a formidable obstacle because of the unfamiliarity with the details of the device bred of lack of experience and of newness. Time, if it were available, would take a sting out of complexity.

Hence the danger we face is that, to attain greater performance within a short time, we utilize the means which first become available without opportunity to simplify or to fully check out the hidden weaknesses. Such complexity is apt to result in unreliability, even though complex devices, fully tested and developed over a reasonable period of time, may be very satisfactory.

Chart 1, page 8.--This chart illustrates the problems encountered in putting a new, complex piece of military equipment into use. This is one of the most complex slides I have ever seen. It was taken from the proceedings of the Institute of Radio Engineers, and was intended to show what happens over a period of time when you put a new and very complex piece of electronic equipment into use. If you will notice the "operator's task" curve on the slide, first, the job for the man who has to run the equipment becomes increasingly difficult. As he becomes familiar with it, it becomes very much simpler. The higher ordinate indicates that the job was something very hard to do, and a lower one shows that it was easy.

If you will notice the reliability curve, you will see the effect of reduced reliability from the new equipment and then increased reliability as problems are solved. The complexity of the equipment goes up as time goes on, indicating that the equipment was made more automatic. The instrument accuracy, which is the curve at the very top, shows that the more complex equipment has resulted in much greater accuracy. The apparatus exemplified in the series of curves is fire-control equipment, but it is not so identified in the publication.

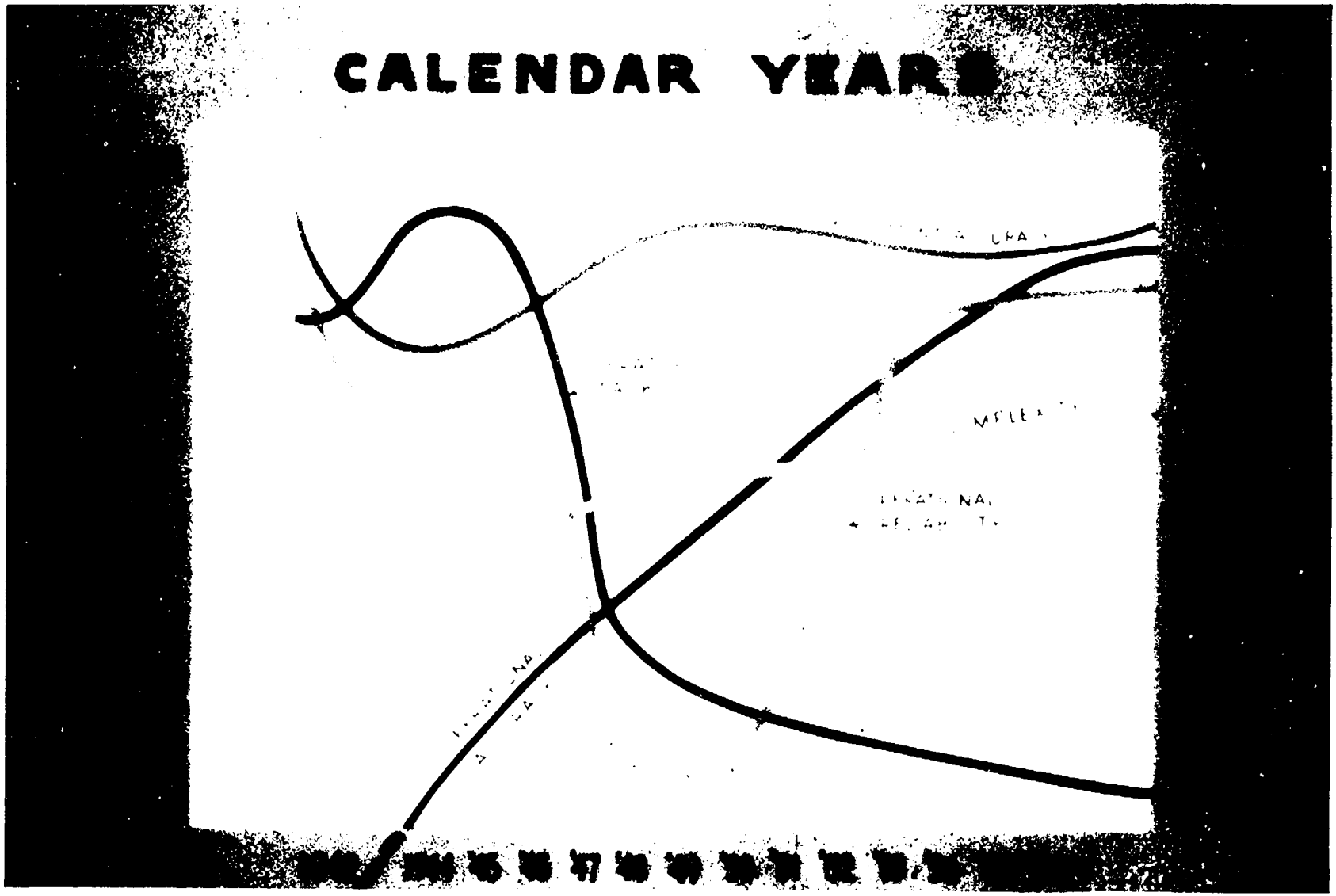
The point which this curve was intended to show is that through experience and time equipment, it becomes more reliable. The initial problems gradually wash out; but frequently we don't have enough time to allow for solution of problems.

Another point which was mentioned by General Smith, and which has become a very serious problem in connection with the producability of the equipment, is that of the time factor--the time to produce.

One of the reasons why electronic equipment is frequently late for delivery is that sometimes it is not started soon enough. There is an impression in some quarters that it takes much less time to design and build a search radar or a fire-control system than it does to merely build the vehicle in which it is to go. It is not possible to design and build the electronics in the time it takes merely to build the vehicle--at least, not successfully.

I submit that time is required to do a good job of designing and building electronic gear. In high-performance equipment, the designer must study the requirements carefully. He must know what is needed, not merely what the specifications call for, but how the gear is to be used. He then embarks upon a program of designing and testing sections of the circuitry. A "Breadboard" model is usually constructed.

CHART 1



Drawings are made and an engineering prototype is constructed. This is tested and changes are made to correct any deficiencies. In the interim, special parts have been designed and ordered, and they are checked out. Drawings are corrected after the engineering model has been tested out--often in a field test requiring several months--and production is begun.

The bill of material is prepared for ordering parts. Manufacturing engineers decide which components are to be purchased and which are to be fabricated. Purchase orders are then issued. Fabrication of parts begins. Schedules for assembly are established. Purchase items are inspected and sometimes rejected and rebuilt. Assembly of subunits is started and they are tested. Changes are made if the toolmade parts differ substantially from the handmade parts used in the model. Final assembly begins; then type tests; and, at last, acceptance tests of production items.

Chart 2, page 10.--This chart shows a typical time schedule for the design and production of a moderately complex piece of electronic gear with most of the steps in sequence. You will note that the planned elapsed time is 154 weeks.

Delivery intervals for purchased items depend largely upon the order board at the supplier's plant and, of course, upon whether the item is a standard one or a newly designed item.

In practice all of the steps are not taken in sequence as indicated on this chart. For example, in order to compress the time, production parts are often ordered or fabricated during the type tests. Sometimes production begins before the type test is carried out. If the article goes through the test 100 percent, everything is fine. If not, the parts must be changed or reworked.

Some processes can be carried out logically in parallel with a minimum of risk. For instance, time can be gained in "breaking down" the job for production while the engineering model is being tested. If changes occur, only certain paperwork must be redone.

I do not believe that the schedule shown on this particular chart would be acceptable in any normal military procurement, because the time element is too long.

As a result, in order to reduce the time element, manufacturers attempt to compress the schedule by paralleling functions.

CHART 2

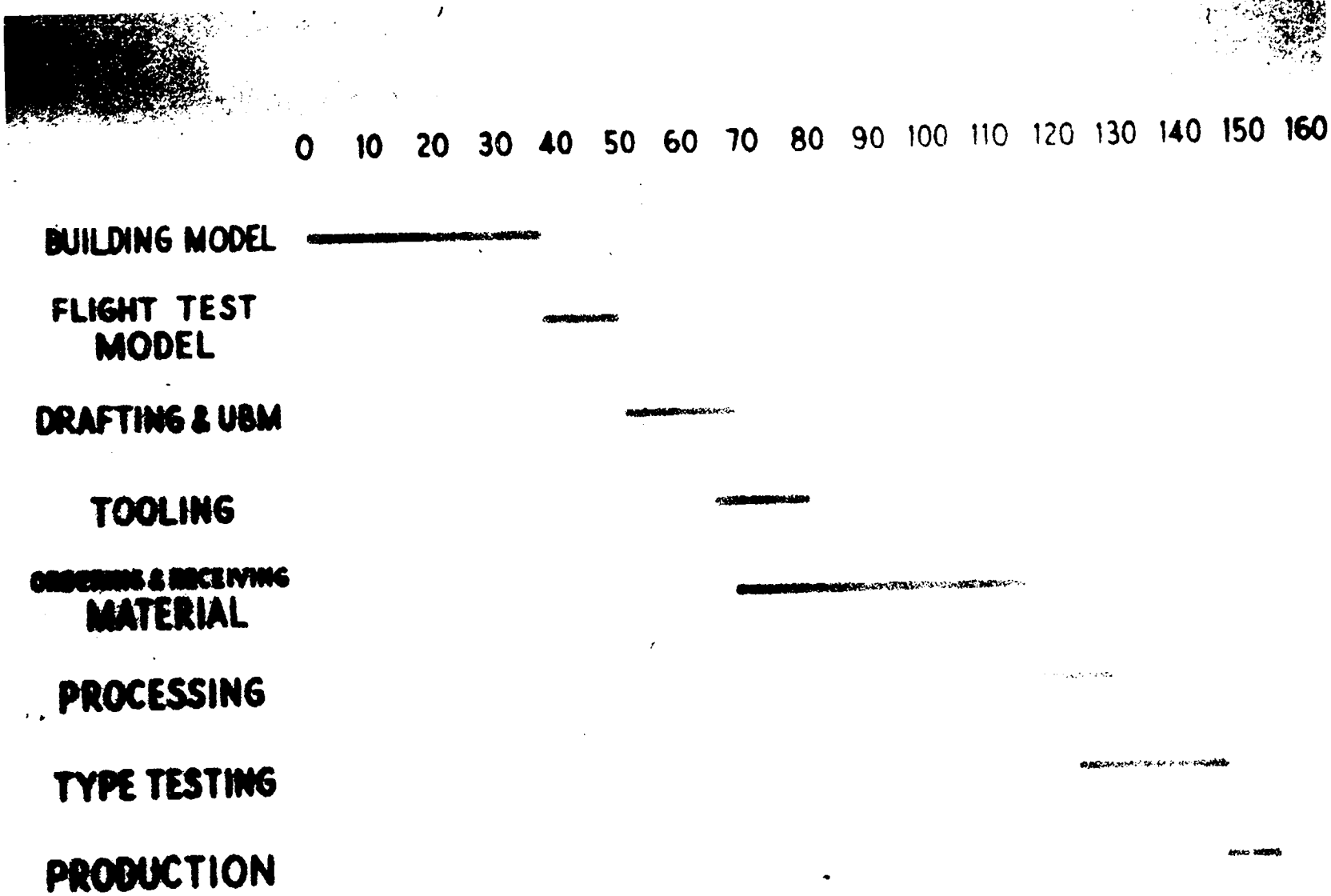

0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160
BUILDING MODEL
FLIGHT TEST MODEL
DRAFTING & UBM
TOOLING
ORDERING & RECEIVING MATERIAL
PROCESSING
TYPE TESTING
PRODUCTION

Chart 3, page 12.--Chart 3 shows how some of these functions can be carried out in parallel. While you are performing one function, such as ordering parts, you are going ahead and doing the engineering work. While you are type-testing the model equipment, you actually start production of the model.

Note that the overall time has been reduced from 154 weeks to 104 weeks.

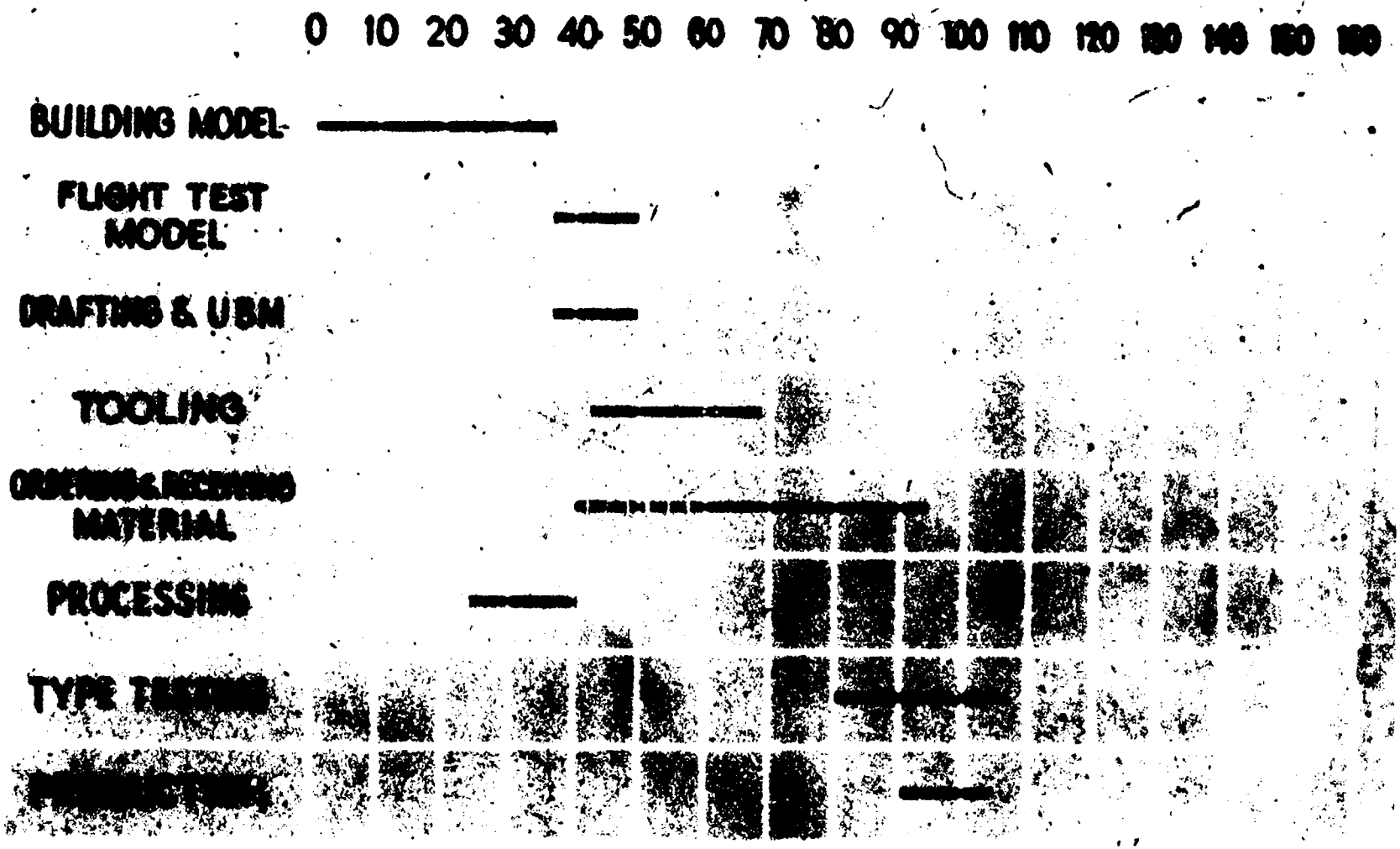
Such compressions are effective if everything works out, with no failures. But, if a parts supplier muffs the ball, or the characteristics of the production model differ from the engineering model, the schedule will not be met. There is no allowance for any major problems which may be encountered. Considering the number of parts in a piece of electronic apparatus and that, to attain the newly required high performance, many of the parts will have been made for the first time, you can readily see that there is a risk of missing such a schedule.

Of course if the equipment is a rerun or merely an older design slightly modified, then the factors of uncertainty are greatly reduced. It is in the field of brandnew designs that a safety factor is needed in our schedules, but seldom obtained.

Why, you may ask, should the production model not be identical with the engineering prototype? I have already mentioned that the latter may be handmade, while the production units are constructed from tools. In dealing with parts whose requirements relate to size, shape, strength, or other physical factors, some problems occur which are familiar to the designers of aircraft or ordnance. But in electronics we deal with a host of dimensions in addition to the conventional ones. We are also concerned with dielectric qualities, resistivity, and magnetic properties, and these qualities assume varying proportions in accordance with the frequency, power, temperature, or humidity. They are not properties which can be detected by the eye or by a gage. They require secondary perception by complex test apparatus. Often their properties are interrelated so that, while some elements by themselves seem satisfactory, in combination, problems are encountered.

I should like to tell you about a gear which caused us a great deal of trouble. Now, gears are not a new invention, and this one, which served to drive a rotating tuning coil, was peculiar only in that it had to insulate the motor from the coil. It was not even a particularly precise gear. Just a gear!

CHART 3


0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160
BUILDING MODEL
FLIGHT TEST MODEL
DRAFTING & UBM
TOOLING
MATERIAL
PROCESSING

We made it of nylon and put it in our model. In the model it worked very satisfactorily. Then, when we operated the completed equipment during the life test, we found that the teeth of the gear would strip. So we redesigned it. We made our calculations all over again and figured out the strength required for the gear teeth, and we added a little more safety factor, and put it in the equipment. Much to our surprise, the teeth stripped all over again. So we had gears built of different material of greater strength. The teeth also stripped. At that point we started a little detective work. We finally found that the gear happened to be located in an electric field from the coil. In the engineering model, because of a slightly different placement of parts, there was no difficulty, but in production the electric field introduced enough heat in the gear so that the teeth softened, and of course the gear teeth then stripped. So what we did in this case was to provide other means of insulating the coil, made the gear out of steel, and had no further troubles.

This was a very simple sort of situation to cope with. Most problems are more complex. Yet there was no easy way to measure the field from the coil with respect to its effect on nearby parts. Many of the effects we encounter are equally intangible yet very important. It makes dealing with conventional physical characteristics seem very simple indeed.

Because of the many added dimensions imposed by the characteristics of electronic circuits, production problems are apt to be more difficult and more time-consuming than in the case of mechanical or ordinary electrical devices. Perhaps I can give you a somewhat parallel example. In the process of printing pictures in a magazine, plates are made and then these require handwork, etching, and other adjustments to compensate for the paper, ink, and so on. In making an average plate for printing in black and white, seven hours may be needed for production plate adjustments. But if the added dimensions of color are added, the plate may require as much as 80 hours of work in the process of production. We must either make proper allowance for the added dimensions of electronics or find new ways to produce electronic equipment.

General Smith made some reference to the cost factor. I would like to discuss that for a moment with you.

The cost of electronic equipment has increased markedly since World War II. So has the cost of aircraft, tanks, guns, and other materiel. A wartime communications set of a certain type cost the Government 1,130 dollars. The equipment set now used costs in the order of 4,000 dollars.

The differences are due to several factors. First, costs have increased generally--compare, for example, the price of automobiles prewar and now. Second, high performance equipment costs more money. An atom bomb, obviously, costs more than a blockbuster. Third, we are not in general making quantities of military products which would result in obtaining the lowest costs. The demands for improved performance result in constantly changed designs so that in many cases, as we get to the point of having production run smoothly and economically, we stop and start all over again.

The starting costs of tooling, training of personnel, acquiring test equipment, setting up a line, become a very major factor, unless production of equipment is large enough to make these fixed costs become small on a unit basis. As taxpayers, we have no desire to see warehouses crammed with unneeded gear. But with limited production requirements during the cold war, costs are bound to be higher.

None of these cost problems are unique to electronics. They apply to all types of military equipment. Expenditures for electronics may have increased disproportionally because more electronics is used today than previously. It is a case that the white horses eat more than the black ones because there are more white horses.

If we are able to permit more time for designing apparatus, if we are able to extend the life of designs by modification rather than by supplanting them with new designs, if we do not expect more new functions of our apparatus, we can reduce costs--otherwise the cost is likely to go still higher.

Now I would like to talk with you for a few minutes on the subject of reliability. General Smith referred to that subject. It is one we consider of the greatest importance today, and certainly one of our major problems. There is no question about it; no matter what we do in improving airplanes, guns, or electronics to make them more reliable, it has a bearing on the cost factor.

I want to leave with you the fact that the problem of reliability will also have an effect on the cost of military equipment and make it go still higher.

In a speech before the Radio-Electronics-Television Manufacturers Association this fall, Mr. W. H. Martin, Deputy Assistant Secretary of Defense (Application Engineering), said in part, and I should like to quote:

"Exposure to the rigorous conditions of combat and to climatic and other conditions far beyond normal experience with civilian electronic equipment produced failures of astonishing proportions. Even the requirements based on World War II experience are in many aspects inadequate for today's conditions.

"The push on the part of the military to get electronics to do the needed, but next to impossible, things, and the eagerness of the electronics industry to meet the challenge, have led to a situation which has put the industry on the spot and poses to it the necessity of taking stock and seeing what can be done to bring about a proper balance."

The Air Force Chief of Staff, General Twining, said in a recent address before the American Ordnance Association:

"Electronics also has given us a lot of trouble. At the speeds and altitudes we operate at today, human reactions are no longer enough to do the job. We must depend on electronic bombsights and gunsights, fire-control systems, radar, and radio sets, electronic engine controls, and so on. One dead tube can have the same effect on the combat effectiveness of an airplane as a dead pilot at the controls. A multi-million dollar bomber can fly halfway around the world but, when over the target, if one electronic part fails, all the thousands of man-hours, millions of dollars, and training and effort has been for nothing. More important, American lives may have been lost for nothing. Transistors will help solve our electronics problem, but truly, the vacuum tube or the transistor is today's counterpart of the famous horseshoe nail."

I have quoted two eminent authorities who feel that there is a pressing current problem with the reliability of electronic equipment. There are many others who feel likewise. In fact it has become so popular to beat the old horse that a number of difficulties only remotely connected with electronics are often attributed to the same source.

However, let us grant there is a major problem and look into it. The subject is one which has a great effect upon the producibility of electronic equipment. With your permission, therefore, I shall explore it as thoroughly as my time will permit. I shall try to outline what seem to me to be principal causes of the problem and offer suggestions for a solution.

One of our greatest present difficulties with respect to reliability is to tell soon enough whether or not the equipment we are producing is or is not reliable. Present military acceptance tests will not in general tell us so. At one time we produced a quantity of sonobuoys. In addition to ordinary inspection, type tests, and acceptance, we were required to submit a number of samples at the start of each week's production for dropping from a plane into the water. The results of such drops determined the quality standing for the week.

This was an awkward way of doing it, but it had many advantages. In some instances the buoys were incorrectly launched, at times planes could not fly, and the question of airplane priorities sometimes arose. Nevertheless, such tests did give a positive answer as to reliability. In many other cases it is not practicable to make immediate tests on production items in the field, or field tests take so long that large quantities of equipments are produced before the results are known. It is too late then to take action, except after the fact.

In the case of new equipment, engineering models are usually field-tested prior to production. However, there is no guarantee that production equipments will behave exactly like the models. Parts and circuits will probably have been changed. Handmade components will be supplanted with toolmade items. All of the parts used in production may not be of the same quality as the original parts used.

We would like to know at once whether the equipment will perform reliably, yet most equipment is accepted on the basis of performance and not reliability. More emphasis is placed upon a hairline variation in specifications than in the number of hours the gear will run. Of course type tests of a few samples are made, but the quantity is insufficient to yield any complete data.

Real field tests in military environment are often of great duration. It is impossible to await the results or production will be long delayed. The sensible course is to devise factory tests which will provide data comparable to field tests. We have attempted, in RCA, to take such a course. By testing a large number of production samples for relatively long periods under conditions carefully devised to simulate normal field operation, we have been able to obtain data, the pattern of which was closely verified by field tests a number of months later. Our factory tests added to the cost, but were cheaper than large-scale field tests and much more rapid. The results could be fed back to engineering and to manufacturing so that fixes could be made quickly and the reliability of the product improved substantially.

Much more work needs to be done to devise tests applicable to various types of equipment. This is a broad research problem which might prove to be of the greatest importance in solving reliability situations. We intend to continue our efforts, but it is evident that no one company can do the complete job. This is something which the Department of Defense could consider. In fact they have already approached the problem.

General Twining mentioned the vulnerability of electronic equipment to the failure of a single part. This is a characteristic of electronic apparatus which is not necessarily true of all other military materiel. Many electronic systems consist of chains with elements in series. The failure of one link disrupts the system. Obviously, the more complex the system, the more components are used, and the greater the statistical chance of failure.

It is clear that as equipment becomes more complex we must become more demanding of individual components. But how much so? We need to know quantitatively the figure of merit we are seeking.

Present specifications as to reliability in military contracts may not be too definite. In general the Government takes the position that the equipment should serve its needs or else the manufacturer will be in hot water, but it usually fails to define what its needs are. That is up to the contractor to find out.

However, by failing to state its requirements in terms which can be clearly understood, the Government is certainly contributing in a major degree to the unreliability of equipment. If apparatus is purchased competitively, how can the bidder decide on the quality to supply when, in general, if he puts more reliability into the equipment he is going to incur increased cost and may lose out in the bidding. This situation not only creates no incentive to provide reliable equipment but places a premium on unreliability.

Some current contracts contain requirements that equipments shall be capable of trouble-free operation for 200 hours. Such methods of specifying reliability are the equivalent of stating that all ball bearings purchased should be perfectly round. Of course they never are. It is necessary to define the limits, if the item is to be produced in quantity. For example, a requirement might be that 9 out of 10 equipments would be capable of operation for 200 hours without failure under a specified series of test conditions. These test conditions should be capable of being performed in the factory, yet should, as I have previously stated,

be related to field experience. Furthermore, "failure" should be defined carefully and should be related to performance.

Now, the higher the percentage of equipments required to meet the tests, or the greater the number of hours without failure, the higher will be the cost of the equipment. Military planners may be called upon to weigh the added reliability in terms of the added cost. Where practicable, in some cases it may be less costly to consider spare equipment rather than pushing reliability to the utmost.

The number of hours of trouble-free use is a matter relating to the service for which the equipment is intended. A piece of shipboard electronic gear should have a useful life thousands of times longer than that in a guided missile. Yet the latter might require a guarantee of freedom from deterioration under conditions of long storage as well as very high reliability for a short period.

With definite specifications of reliability, all manufacturers would be placed upon an equal basis in designing equipment and in bidding. The area of interpretation of reliability would be minimized. The Government should be able to procure products of known reliability and could prove it by test.

I hasten to explain that the procedure I have suggested is presently costly and difficult to put into effect. I stick to my guns, however, that it should be our goal for the earliest possible realization.

Why is it difficult? Because to achieve the desired degree of reliability, we must be able to rate each of the thousands of components used in a complex electronic device in the same manner. We should know that the resistors, for example, would be capable of operation without failure at the rate of 999 out of 1,000 for 200 hours. By selection of suitable reliability index figures, we could then design satisfactory end equipment.

In general there are no ratings available for components. We are flying by the seat of our pants. If we happen to run into bad weather there are no instruments to guide us. Some work has been started in this direction, however. In our company, we are testing sample-purchased components in lots, operating them under service conditions for long periods and thus establishing tentative ratings for our own use. Frequently such tests enable us to suggest modifications to the manufacturer which result in a substantially improved product.

Many of the components used in electronic apparatus are manufactured by small companies who do not have either the technical or the financial means to run large-scale tests of their products under various conditions which are not presently defined.

Furthermore, a substantial portion of their business--and often the most profitable--may fall in commercial categories where such ratings are not needed because with continuous production ample data are available to control quality. Hence, there must be some incentive for them to determine the rating of their product for rigid military environmental use.

The needed quality of components in a complex device is a terrifying factor. If an equipment contains 10,000 components, as some do, and if the average failure rate within the desired life period of each component is only one in 10,000, then, statistically, every equipment may fail. We would need an average failure rate for the components not exceeding one in 100,000 to obtain an equipment failure rate of only one in 10 during the life period.

It is pretty obvious that no one can possibly test 100,000 of every one of 10,000 components for, say, 200 hours. This would mean 2×10^{11} total test hours or some 20,000,000 years, assuming that there were no common items used. Fortunately, however, we do have a number of common types of components so that we can life test, but it is a formidable and costly process all the same. A large percentage of the components produced would need to be tested for life to establish significant data.

But there are also practical things which can be done. We can accumulate various types of data which will provide us with a rule-of-thumb rating. We can analyze data from field reports on the failure of components in equipment . It then becomes possible to direct our attention to those items most responsible for our troubles. We can devise accelerated life tests in some instances which may provide clues as to what will happen during normal life. Tests, for example, under extremes of temperature, both cold and hot, may possibly reveal defects quickly which would normally occur later. We can test more exhaustively the items which are more subject to wear or deterioration. We can study the importance of sudden failure versus normal deterioration and determine which causes the most trouble in any item.

In some instances it may be cheaper to duplicate circuit elements and to use "redundancy" to provide additional reliability.

We can utilize the "shakedown" technique for components or end equipments. Experience indicates that, in general, latent defects are likely to be revealed within some period of "shakedown" operation.

Chart 4, page 21.--This chart shows that if you take a new piece of electronic equipment and run it for a certain length of time you are apt to have more failures during the initial period than later. You will notice that after a certain number of hours the equipment becomes shaken down and more reliable. We are taking our electronic gear and running it a number of hours before we ship it. In this way, we in RCA, hope to find out hidden defects which otherwise would not appear until later.

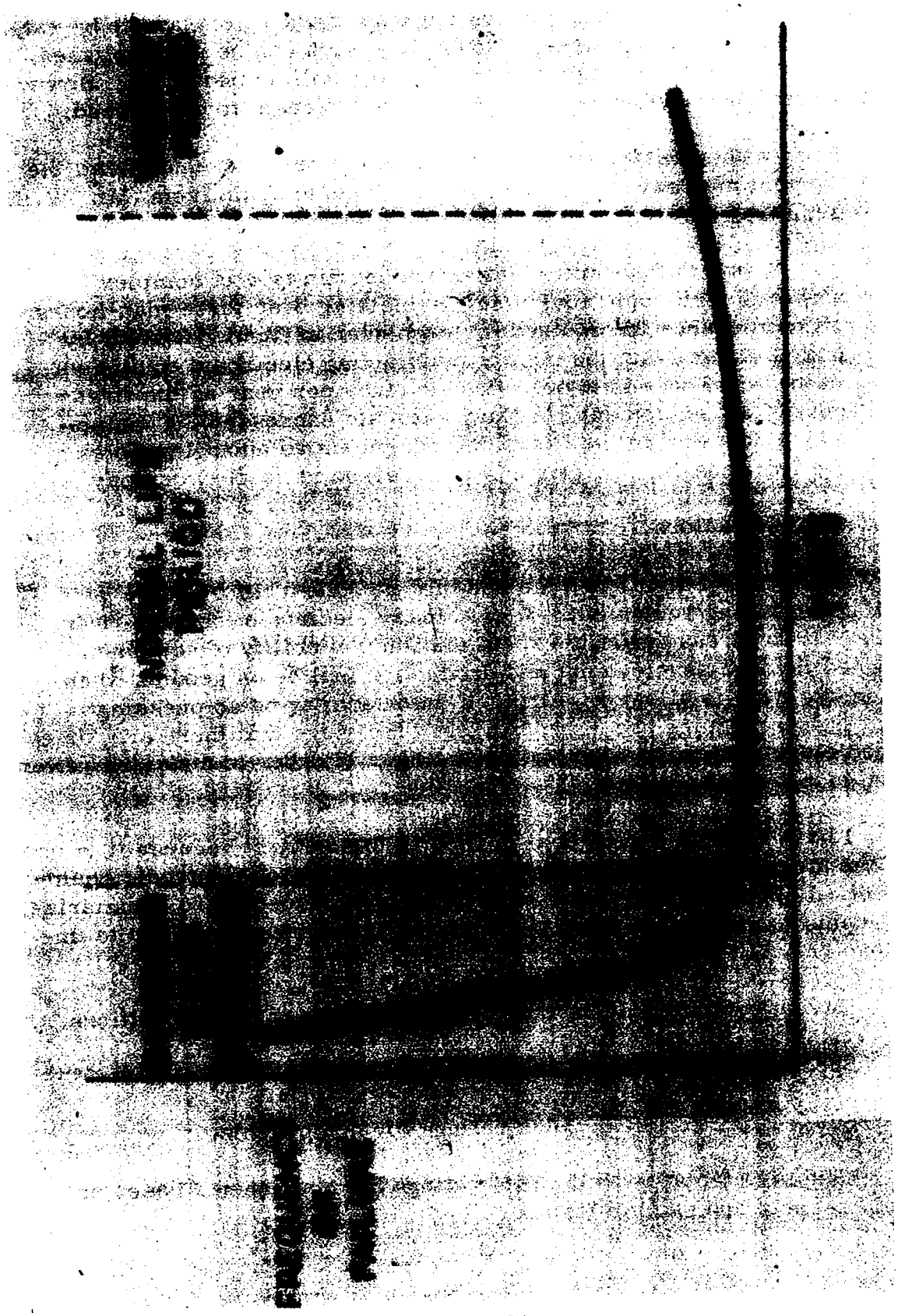
It is essential, however, that we have an adequate feedback of information as to failures and their causes, and that careful statistical analysis be provided in order to improve components and to provide equipment designers with adequate working data.

Recognition of the problem of component reliability has certainly occurred within the industry. Radio-Electronics-Television Manufacturers Association groups are studying the problem. Mr. Martin's office has established an advisory group on Reliability of Electronic Equipment, under the chairmanship of Mr. L. M. Clement, whose membership includes representation from the electronics industry and the military. A few tubes have been tested and reliability index figures established. Component manufacturers are taking action also. Nevertheless, much remains to be done to solve the general problem of component reliability.

An allied problem affecting reliability is that of workmanship in assembly. This is a broad subject, but I should like to point out that, in large production, good workmanship is achieved economically by continuous production which permits workers to become familiar with the demands of the specific job. Workmanship problems are accentuated by interruptions which result in new labor taking over and going through a learning period.

If we are to achieve the goal of greatly increased reliability, we will almost certainly find that the equipment will cost a great deal more, at least in the initial stages. Without complete data on component reliability, we will tend to lean over backward in order to play safe. We may have to "overtest" in order to be sure. We must go through this stage in order to

CHART 4



make progress. If manufacturers engaged in such work are to be rated by competitive pricing alone, I doubt that much can be accomplished, since those who put the most into reliability will be penalized. However, with experience and knowledge we may expect costs to be reduced.

Even with substantially greater costs for reliable equipment, the Government may save very large sums. I quote again from Mr. W. H. Martin:

> "I was told recently that, for a certain type of complex airborne electronic equipment, something over three man-hours of maintenance is required for each hour in flight. A study by RAND showed that the cost of maintaining electronic equipment in the Air Force is about twice as much per year as the first cost of the equipment. A Navy estimate expressed the maintenance cost during the life of the equipment as about ten times the first cost. . . . Obviously increased reliability can pay large dividends--with account being taken only of the direct tangible factors."

I previously mentioned the need for sufficient time to do a good job in producing equipment. A good many electronic jobs are rush jobs. It is unreasonable to expect that the reliability of equipment rushed through development and production will be as good as when adequate time is allowed. At times the need may be so pressing that rush schedules are essential, yet I feel sure that there are times when older equipment might be used longer in order to make the newer design more satisfactory.

I have devoted a good deal of time to this subject because it is one of the most important aspects of the producibility of electronic equipment. I have dealt with only a few of its many facets. To summarize, it seems to me that we need to do the following things in order to improve reliability:

Devise equipment tests more representative of field conditions.

Specify desired equipment reliability in detail.

Set goal of reliability index ratings for components.

Establish tentative reliability ratings for components based on field reports and sample tests.

Establish test methods to accumulate accelerated component life information.

Recognize the value of "shakedown" testing.

Plan for continuous production as much as possible.

Do not penalize manufacturers who strive to make reliable equipment.

Allow sufficient time to do a good job.

What can we do in order to plan for greater reliability in producing our equipment ?

First, with respect to design development leading to production, I believe that the present methods of developing, producing a quantity, and then starting a new development program, often with another contractor, should be considerably modified in order to solve some current problems. The present methods too often are wasteful of engineering resources, know-how, and production capabilities. The following is a suggested procedure for conserving resources and making for better producibility.

The contractor selected for development of an important equipment should be qualified to a high degree for both engineering and production. He should be willing to make a long-term commitment for such a program. Inasmuch as the development cost is usually minor with respect to production and maintenance costs, emphasis on development cost should be minimized. I believe the Government will save money by spending adequate sums on development and not selecting bidders on the basis of competitive pricing but primarily from excellence of proposals and other qualifications.

Next, after a design has been completed, models tested, and production deliveries started, factory reliability tests which I have described previously should be undertaken. The specifications for such tests should be a part of the original contract. I also feel strongly that it is impossible to assure satisfactory results unless the designer is also the initial producer. Successful equipment designs cannot be made without the benefit of production experience on the equipment. To assign a design contract to one contractor and the first production responsibility to another is to relieve both of responsibility and to leave the Government holding the bag with a design which may or may not be producible.

As soon as possible after production has begun, field tests should be started. These may be special "proving ground" tests made in military environment; they may be tests upon actual permanent equipment installations carefully observed and under controlled conditions to eliminate irrelevant factors.

The same contractor should be required at once to undertake an improvement program and redesign of the equipment based upon production experience and the result of field tests. The design engineers should not only have access to field data but should be present during some of the tests. Utilizing their experience, both within the factory and in the field, the design should be modified in order to provide greater reliability, to reduce costs, and to accommodate the design to the problems of using personnel.

The quantity ordered for initial production should be limited until the redesigned apparatus can be delivered. The initial production should be considered as a pilot run, not intended for permanent usage, but to be replaced by the final redesigned gear.

The pilot-run equipment serves a number of purposes. It serves to provide production experience. It enables field-testing to be accomplished. It serves as the springboard to lower costs and better quality.

Similar, but less comprehensive field tests should be run upon the redesigned equipment. These may be regarded as a check upon the modifications and to verify the factory-life tests.

The contractor may, at this point, engage in large-scale production with reasonable safety, and the Government may, if desired, now set up a second source of supply. It would, however, be highly desirable to retain the original contractor under development contract to improve and simplify the apparatus throughout its useful life, which, by the way, can usually be considerably prolonged by such means.

Objections may be raised that such a procedure is wasteful of time and may be expensive. I submit that other methods may appear to save time and money initially but really may be extremely wasteful. I am convinced that such an orderly program would save vast sums, would result in much more reliable equipment, and would have fewer missed schedules than at present. I believe that the equipment would become more simplified and operational problems would be greatly reduced.

I should like to make it clear that I have not included broad systems development programs in my previous comments. I have referred chiefly to development work leading to the specific design of hardware.

I should like to emphasize again the need for a broad research program directed toward methods of rating components for reliability and for improving component life . I would even suggest that some funds intended for end products could well be diverted to component development and pilot-run production in order to assure a broader base of reliability.

Example of a Long-term Program.

I should like to cite an example of a program of development and production in which our company engaged and in which a number of benefits to the Government were realized. While this program did not include a separate pilot run, the first 50 equipments were assembled as a pilot-run lot. It included a long-term improvement program which has resulted in lower costs, greater reliability, and in equipment simplification.

The program was the AN/PRC-8, 9, 10, low-weight Signal Corps Walkie-Talkie. In June of 1946 RCA was awarded a development contract to the amount of 279,000 dollars. The purpose was to develop a unit smaller, lighter, and of greater effectiveness than the World War II units, which had been dubbed "Backie Breakies" by the GI's. The result of our development was a unit in which bulk was cut down 35 percent, and the range of usage was substantially increased.

Chart 5, page 26.--This chart shows a comparison between a PRC-10 and the predecessor model. You can see it has been substantially reduced in size, also in weight.

In order to accomplish the size reductions, we had to utilize miniaturization techniques and even to develop new, smallsized, components.

Charts 6 and 7, pages 27 and 28.--These two charts show the construction of the set with the subminiaturized parts. You can see it is pretty well packed in.

A number of development models were built by our engineers and tested by the Signal Corps in succession until, in 1949, the latest model satisfied the Army's requirements.

In 1950 RCA received a production contract and, because of Korea, every effort was made to expedite production. By means of excellent

1260

CHART 5

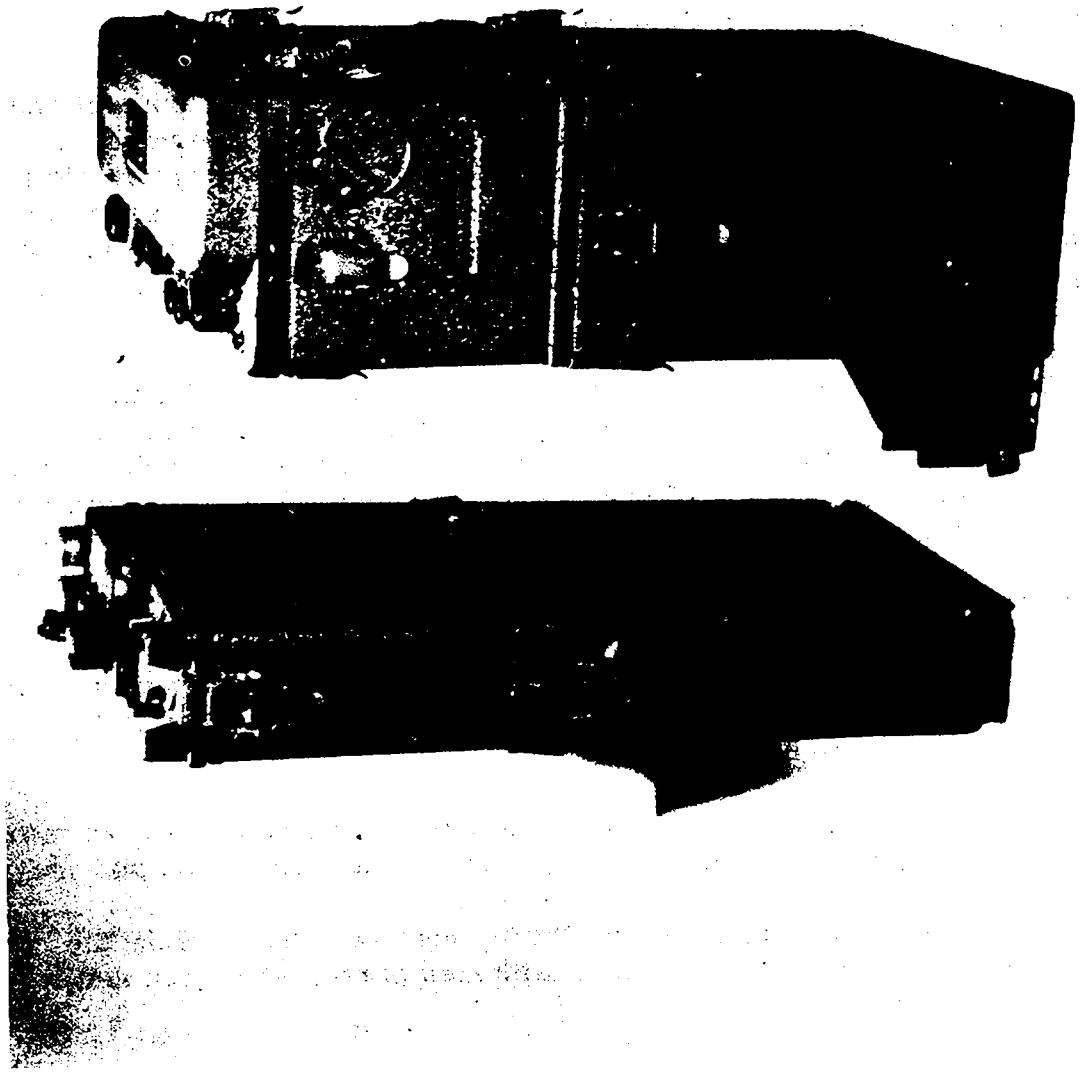


CHART 6

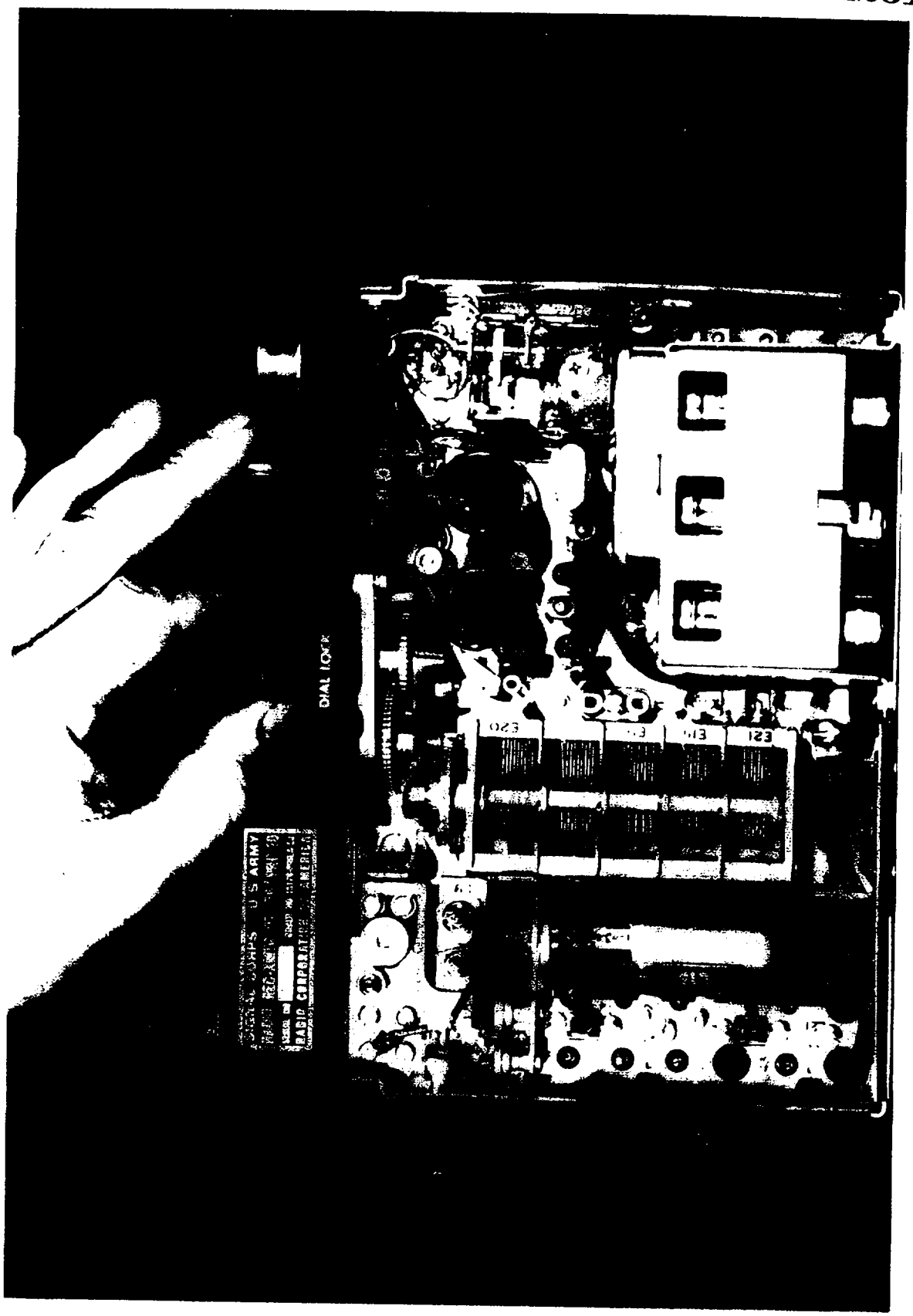
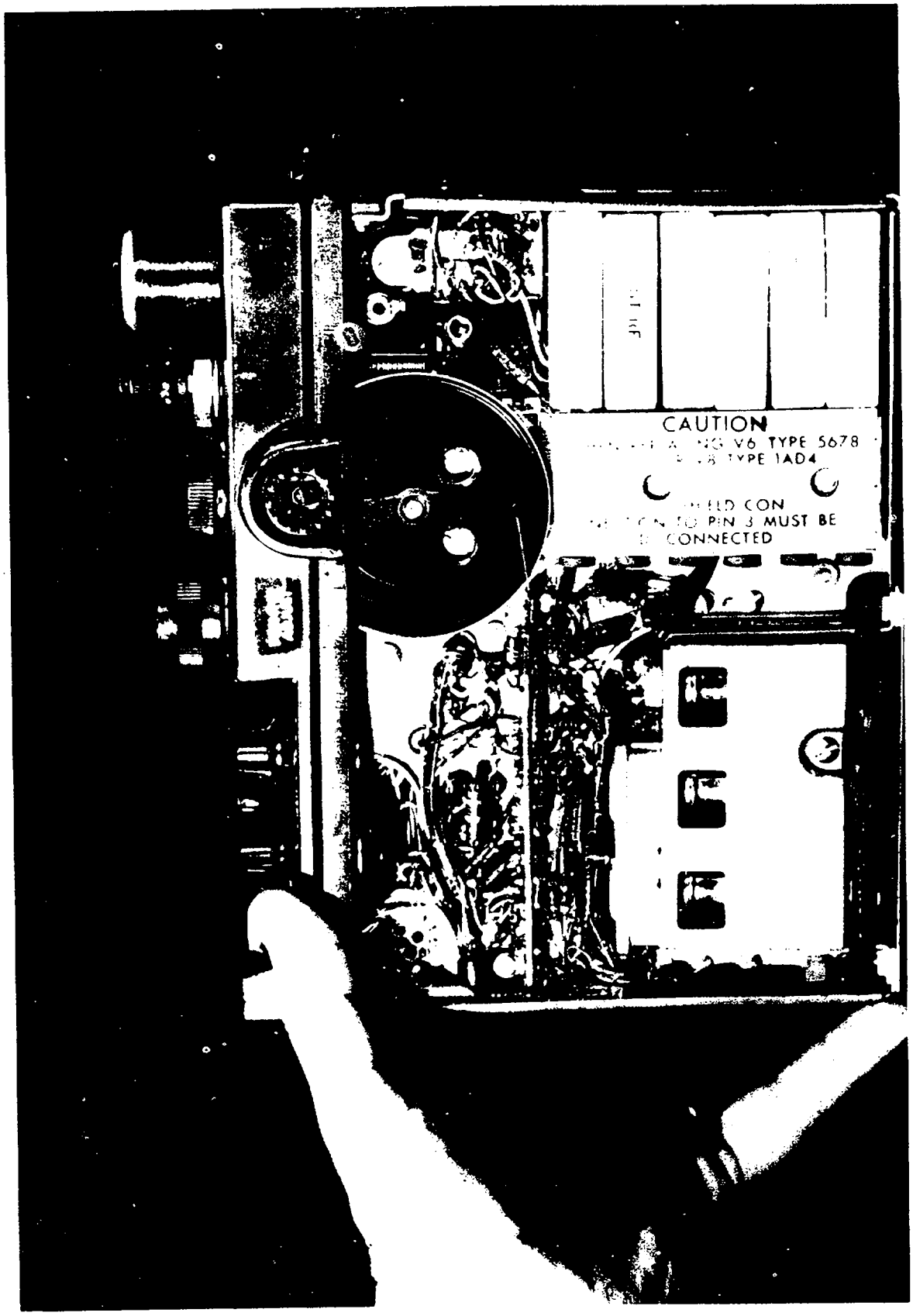


CHART 7



teamwork between Signal Corps personnel and RCA production personnel, the first equipment was delivered in 36 weeks.

Chart 8, page 30.--This chart shows a PRC-10 equipment under battle conditions in Korea, where it provided a flexible, effective means for coordinating infantry with armor and artillery. This was frankly a crash job. Not every job can be so handled and more complex equipments would require a longer time to produce.

Chart 9, page 31.--This slide chart shows the time required for the various functions, in weeks, from the inception. These total 55 weeks, but many of the functions were carried out in parallel--for example, fabrication of parts and purchasing of components. I mentioned a moment ago 36 weeks as the actual delivery cycle.

In order to gain production experience, 50 sets of parts were rushed through. These were assembled and the finished sets carefully checked. By means of this pilot-run procedure, production techniques were firmly established, personnel were trained in the use of miniaturized parts, and performance of the sets was measured.

The Signal Corps utilized the initial 50 equipments for evaluation and test, and preliminary life tests of the equipment were made. The unit price to the Signal Corps on this initial order was 579 dollars. RCA lost 1,414,000 dollars on this fixed-price contract due to rising labor and material costs and to the problems of producing a new, advanced equipment.

Chart 10, page 32.--This is a humorous commentary on such a situation. The caption is self-explanatory.

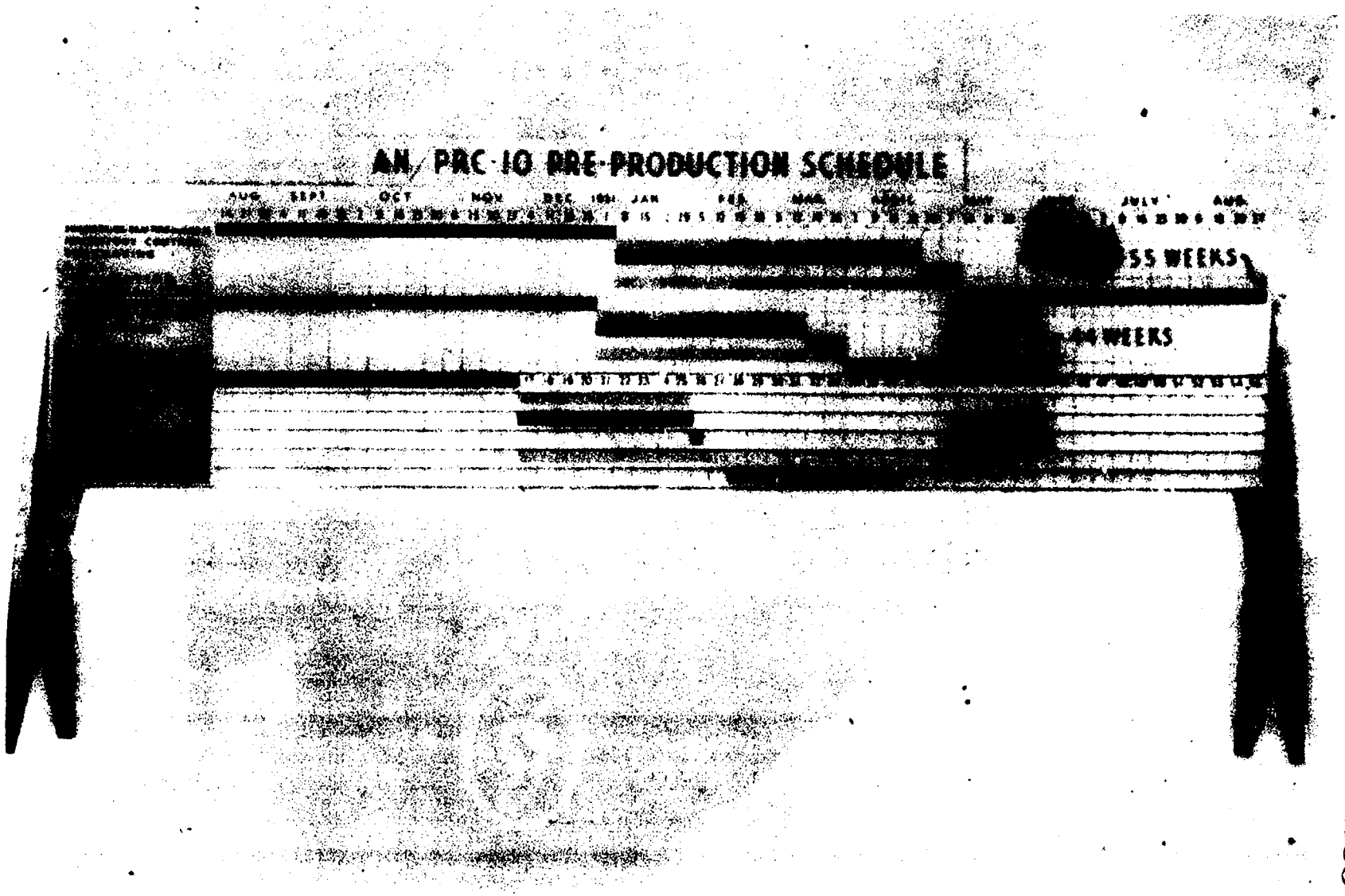
However, the Signal Corps went along with us on a long range cost-reduction-and-improvement program, and our later contracts resulted in moderate profits. The initial cost-reduction program resulted in a 12 percent reduction after nine months of production on the initial contract.

In July 1952 we were awarded a development contract for improvements based upon field experience in Korea. Equipments embodying design modifications based upon this contract are now being delivered.

We have also undertaken development on a transistorized Walkie-Talkie, the model of which is substantially smaller and lighter in weight than the PRC-10.

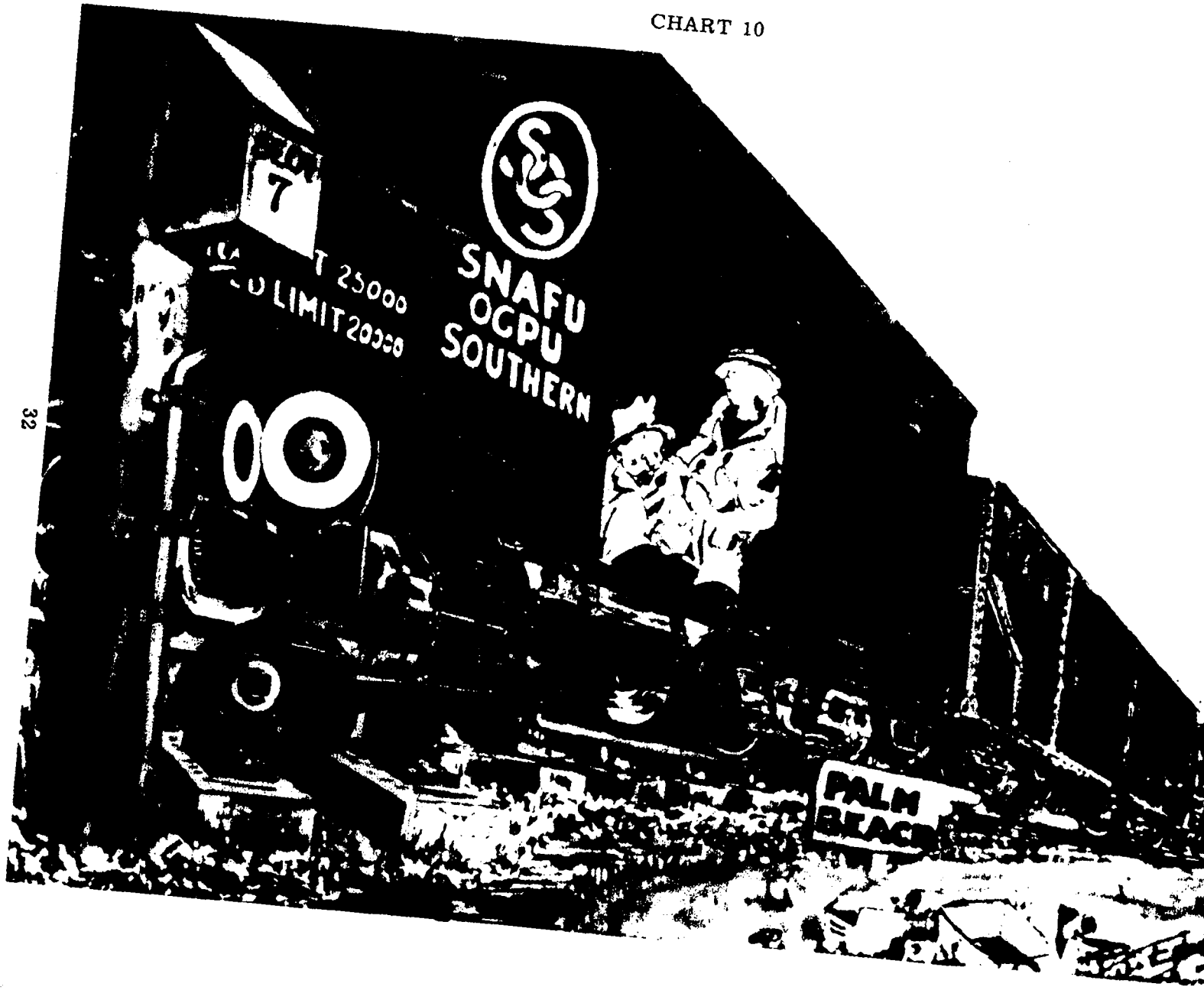
CHART 8

CHART 9


AN/PRC-10 PRE-PRODUCTION SCHEDULE
AUG.
SEPT.
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
JULY
AUG.
55 WEEKS
44 WEEKS

1265

CHART 10



In all, to date, we have received development contracts amounting to 600,000 dollars and production contracts totaling approximately 30 million dollars. The price of the PRC-10 has been reduced from 579 to 468 dollars per unit, and we have recently quoted 330 dollars in spite of substantially increased labor costs during this period. The product has been simplified and made more effective. The program has been continuous and our engineering and production know-how has been utilized to the utmost.

Shortly after our first production delivery began, a second source producer was established. We gave him every possible help and continued to render engineering assistance to him during several subsequent orders.

This is a somewhat unusual situation in that a continuous program was established for a single equipment lasting eight years. Production requirements of the PRC equipment will be essentially completed this year. But we hope, based upon our latest development work, to continue as a developer and producer of Army field communications equipment and to utilize the experience and knowledge we have gained during this eight-year period.

I have here on the table two samples which we have just delivered to the Signal Corps, and I would like to show them to you. This (indicating) is a miniaturized and transistorized receiver which will work with the Walkie-Talkie. Another development is this miniaturized set (indicating). This type is both a transmitter and a receiver--you can talk and receive with it.

I will leave these sample here and during the break, if you want to use them, you are welcome to do so. These are the latest models. You saw the size of the PRC-10. This is the size we can make it today.

Gentlemen, simply in summary I would like to say: I am convinced that by cooperation between the Government and industry, reliability problems will be solved. I hope that a concrete program can be adopted to speed up results.

I believe that the use of printed circuits and automation on which many of us are busily engaged will help to solve some of our time problems as well as aiding in industrial mobilization. RCA has already undertaken to redesign on its own initiative, specific military equipments using printed circuits and modular construction adapted to automatic assembly. Our plans are to hand-construct such equipments until such time as the

assembly machines which we are developing will be completed. We can see many advantages from such a program--greater uniformity of product, easier maintenance, improved reliability because of fewer soldering problems, timesaving, and, ultimately, lower costs. All of these mean easier producibility.

It is obvious that in this limited discussion on the producibility of equipment there has been no opportunity to discuss other elements of the problems which fall outside the subject scope. In connection with reliability, the initial design of the apparatus is obviously of basic importance. The need for proper field maintenance and support, personnel training, and adequate field-test equipment must be emphasized. With high-performance equipment it appears necessary to reexamine the methods for maintaining and servicing apparatus in order to assure satisfactory functioning. No one element can be neglected at the risk of having the entire system fail.

I have tried to outline what seem to me to be the major problems of producibility of the new, high-performance apparatus used today. We have, since the last war, gradually moved toward the frontier of scientific knowledge in building apparatus. We have put this equipment into production because the results of using it would give us a marked military advantage. Progress of technical achievement has been more rapid than that of the design of components, of test methods, and of military logistic support. Industry and the military have begun to understand the problem. With the same force which has resulted in our technical advances applied to find the solutions, we should have answers which will enable us to reach our goal of technical superiority with practical producibility.

Thank you very much.

COLONEL WALKER: Gentlemen, may we have your questions? I might start out with one, Mr. Smith. We were talking about your example of the long-time factor of testing the equipment. On such a volume production, do you use any statistical control methods in your production?

MR. SMITH: Yes; we use quite a number. We use the ordinary type of statistical control of production by sample tests. But we recently have started an engineering development program of testing very large quantities of subassemblies and of components which we use in our equipment and from that trying to draw the theoretical reliability factor of the complete equipment. We think we are beginning to get some results which look very interesting.

QUESTION: Mr. Smith, we have had in the Army, and I know the Air Force and the Navy have had, too, the problem in the past of establishing orders on the basis of an economical production. What in your company do you consider, and how do you determine, what an economical production would be?

MR. SMITH: That is a very difficult question to answer. It varies with different kinds of equipment. It is hard to answer because, for instance, we built a million-watt transmitter for the Navy. The quantity was one. That was an economical production, because it was such a large unit.

QUESTION: How about the PRC-10?

MR. SMITH: Well, what we ordinarily do is try to cost the item in terms of various quantities. For example, we might cost on the basis of a thousand, two thousand, three thousand, four thousand, and we give such estimates to the services so that they can judge costs in terms of their requirements and select a reasonable quantity. I don't think there is a fixed rule. Of course the more you make the more the cost goes down. In general I would say that on very small equipment the production run that is economical runs into the thousands; on large equipment it runs in the hundreds to thousands; on very large equipment it can be one or two.

QUESTION: I would like to make some observations here. Since no one else is sticking up for the Government, I think I will. But it is a pretty hard thing in the Government to develop control or guidance. I don't think it has ever been set out. There have been and perhaps are people here who have been in research and development (R&D). My remarks are not applied primarily to RCA--it is one of the better suppliers--but to the industry in general.

The facts took a little beating in your talk, sir. I think many facts which ought to be, are not covered by specifications; but we think the manufacturers themselves should be handling them. I have been in control of a direct K-system at times. As a matter of fact, at times, in putting in those test tubes, the design for overload on the job was not adequate for what the tubes would be used for. It is a basic problem in engineering on any basis of running temperatures 200 or 300 degrees above what the tube was designed to stand.

This is something you can't cover in specifications. It is a matter of integrity in the manufacturer's process and engineering. In the

specifications there are already certain stipulations set by the manufacturer that the tubes must be designed around standard tubes. We in the Air Force and also in the Navy have a terrific problem here, that the manufacturer's design was of selected tubes. They took standard categories and selected those within special categories of dealers. We can't buy standard tubes which we can get economically and supply all over. We have to buy specific tubes which the manufacturer has bought, tested, and selected as specific prime tubes; and a share goes on his cost and adds to the price. This has to be designed. But this situation is almost under control.

There are a couple of other items that came up. There are impressions that come up--I don't think they are deliberate--but nevertheless in the audience we feel them. On testing the design of components I had personal experience back in 1946, 1947, 1948, and 1949. There are many contracts on which we tried to put out development exhibits which we sent out to given manufacturers to get them to work on major components. We couldn't get the interest of the industry because they were busy with television. If they are interested, they will take the contract; if they are not, they won't take it. I think this is a serious problem in the development of better components. Putting Government dollars into it doesn't do the job. We must have wholehearted industry cooperation.

There is one other problem. You mentioned the fact a couple of times, I believe, sir, that contracts are often let out to a manufacturer on a competitive basis where another manufacturer has done the developmentally basic work. It is my impression, and perhaps you will want to comment on it, that we in the Air Force, where we give out a development contract, almost invariably take the primary contractor for the production of the equipment. Many times, of course, we have to bring in a second source, or a third, or a fourth. We get into more unsatisfactory schedules as to responsibility for further design improvement where there are many sources working on the same equipment.

Basically, since most of our R&D contracts are negotiated under fixed prices, when there are competitive contracts, naturally we head into a matter of policy on production contracts to some agency.

I think the situation you mention is more or less an exception.

MR. SMITH: You brought up some very interesting subjects. May I comment on them now? Let me take them backwards, starting with the last one. I gave the example of the PRC-10 equipment. We developed it. It was let out for competitive bidding. My recollection is that there were 28 bidders on the equipment before anyone had made it in production.

The bid was awarded to a company which had very little production experience just before Korea. That company never did produce.

I think what you say is important. Many contracts for initial production are given to the company doing the development. But there are other situations, and some of them are occurring right now. I also realize that there are policy situations with which the military must cope. These have my sympathy, and I understand that sometimes it is difficult to proceed without considering all such factors.

The component situation that you mention is a very true one. This is a peculiar thing about the electronics industry. Many of the components are produced by small companies. It is difficult to get some of these companies interested in improving designs since most of their money is used up in producing commercial items and they have no certainty of recouping development costs. Actually RCA has placed development contracts and is paying some of these component manufacturers to develop better military components. We are using our own money, simply because we cannot buy certain components which we need. It is a current problem.

I think quite a bit of progress has been made, particularly, in the Department of Defense, in encouraging smaller manufacturers to do a better job.

When you spoke the first time about military specifications, you said that perhaps I was a little unfair. First, let me say I admit it. What I am trying to do is urge that you make improvements in the specifications. The point you mention, on tubes, is one I can speak on with great feeling. We have been trying to use tubes subject to standard military approval and specifications . Let me illustrate.

Standard limits on tubes are supposed to fall within an area defined by this distance (indicating). Any tubes which fall within that area are O. K. We have been using these tubes for complex military equipment. What happens? Many of the tubes are right here on the edge of the limits (indicating). There are few in the center. After tubes have been used a small number of hours, a number fall outside the limits. We can't make equipment that works well when the tubes are outside limits. We have set up new specifications for tubes which require that the average of their characteristics fall in the middle of this permitted area. As a matter of fact, the Government has now adopted this principle of the RCA specifications for some tubes as standard. Specifications are being revised and will become new military standards.

This was a problem we didn't know about previously. Neither did the military. We are finding out such things today. We find the military component specifications are not adequate in some cases in order to design high-performance equipment.

If I have accused the military of making inadequate specifications, let me say industry is equally responsible. We didn't know the answer either until we crossed some of the new frontiers. Now a better job can be done on the specifications.

Thank you for bringing this up. They are very interesting points.

QUESTION: Before I start, let me say I own an RCA television. On this ear-phone equipment, do you run into the same difficulty in applying the ear phone to commercial equipment that you do in applying it to military equipment?

MR. SMITH: Since the speaker of the question is a man of such discrimination, I will try to answer the question very carefully. I think the answer is that usually there is not such a compelling time factor. In other words we can take several years to design a piece of commercial gear; but usually the requirements and the needs for the military equipment are such that you have to rush a little bit more. I think that is the main difference.

QUESTION: I would like to know what the difference in the results are in your experience in the performance and operation of the equipment.

MR. SMITH: That is a very hard question to answer, because the situations are certainly not comparable. For example, frequently the performance requirements of the military equipment are higher. We also have the situation that the people who use the equipment in the commercial area are usually more experienced. There is a great problem, as you know, in the military where people who are experienced with use of this high-performance equipment are in for a certain period of time and then out, and it is necessary to train new people. It is a problem to get experienced personnel to service and use the equipment. It is a very serious one and I do not know the answer.

I think in those two areas are some of the major differences.

COLONEL WALKER: Mr. Smith, you have certainly given us a very interesting and practical talk this morning on this very complex problem of producibility. I don't think we will take production for granted. On behalf of the Commandant and of this year's class, thank you for being with us this morning and contributing so much to our course.

Thank you very much.

(23 Feb 1955--750)S/mmg

A54715