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- USSR -

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## SOME PROBLEMS IN CYBERNETICS

-USSR-

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## THE DEFINITION OF CYBERNETICS AS A SCIENCE

At present, there is no generally accepted, synonymous definition of the term "cybernetics". However, we feel that much controversy over the subject matter and fields of application of cybernetics may be settled if we accept its definition as the science which deals with laws of control by means of complex dynamic systems. Such dynamic systems exist in unique form both in living things and in human society. These systems, capable of changing their state, are formed from a great number of simpler, interconnected and interacting elementary systems or elements. The state of a complex dynamic system, on the whole or with respect to its individual elements, is characterized by the value of one or several parameters which vary in accordance with different laws. The transition of a complex dynamic system from one state into another is called a process. The transference of a system from one state into another by acting upon its parameters is called control.

Three different fields of control should be differentiated: The first is control by a system of machines which carry out processes, and in general, processes which take place during some purposeful action of man on an object of nature. The second, control of the organized activity of a body of people who are deciding some problem or other. For example, bodies and organizations carrying out military, financial, credit, insurance, trade, commercial, and other negotiations. The third, control of processes which take place in living organisms. To this field belong the highly unique physiological, biochemical, and biophysical processes connected with the metabolic activity of an organism and directed toward preservation of the organism under the changing conditions of existence.

All of the stated cases demonstrate complex dynamic systems in which some spontaneous or constrained process of control is realized. That which generally takes place in these processes or control operations is the subject matter of cybernetics. Therefore, the task of cybernetics is to study control processes in complex dynamic systems and to increase the effectiveness of human activity.

Cybernetics is based on advancements in a number of fields of modern science and technology and, in turn, enhances their development.

In all complex dynamic systems, control is carried on by receiving, storing, and processing information. Any control begins with gathering information on the course or procedure of some process or other. The information is changed into a form suitable for transmitting along communications channels and putting into a control organ (for example, the human brain or an automatic machine). Employing definite rules and possibilities, the control organ reprocesses the information in accordance with prescribed tasks and purposes. Thus, a control command is worked out, which also is passed into the executing mechanism or organ. Any type of control is accomplished by the scheme. The concept of information is one basic to cybernetics, but information theory occupies an essential position in the complex of cybernetic disciplines.

#### PRINCIPAL TRENDS OF DEVELOPMENT

Actually, man has been using cybernetics methods for a long time. Whenever some type of complex developing process took place and its control was necessary to accomplish a definite purpose in a given time, people employed methods which, in our time, would be called "cybernetic".

For decades attempts have been made to solve the problem of control by organizational and technical means. However, the most acute problem of control has become evident in our time. In proportion to the increasing complexity of industrial and technical processes, the growth of interaction among great numbers of people participating in economic, political and military activities, and the bringing-in of much material means and power resources, conflicting requirements began to arise in the improvement of control, which, in this case, was to make everything more and more operative and accurate, based on accessible and current information and practical possibilities for such improvement in view of the organizational structures and technical means being used.

For control by complex dynamic processes, it is necessary not only to see an ultimate goal, but also to know the causal relationship within the individual elementary processes which form a complex process, and also the relationship between these processes. It is necessary to understand the relationship between these phenomena as a whole. For this purpose, one must utilize the complex apparatus of modern mathematics, in particular, statistical methods and probability theory. The development of these branches of mathematics, and also the general theory of relativity, information theory, theory of errors, mathematical logistics and other disciplines, great advancements in modern science in general - all of these things warrant a restatement of the problem of control, making them the subject of a special scientific discipline. A decisive role in this

affair has been played by the wide and intensive development of advanced technology and, most of all, electronics - automatic electronic machines and electronic computers. Once, lack of sufficiently effective technical means slowed the development and improvement in the quality of control. Now these means are available, and their expedient utilization for improving the quality of control is the main problem. For this reason, in this decade, in answer to the arising demands of life itself, a new study of control, cybernetics, has been conceived and has begun to develop.

The American mathematician Norbert Wiener initiated the separation of cybernetics into a separate discipline. Wiener perceived the general laws underlying control by the complex dynamic systems which belong to various fields of human activity and living things, and proposed the problem of studying these laws and using them for the solution of practical problems.

Speaking of cybernetics, it follows to mention that it celebrates its generalization and cooperation, on a new basis, with a whole series of earlier existing branches of science: the physiology of higher neurological activity, the theory of automatic control, information theory, the general theory of relativity, statistics, mathematical logic, etc. Cybernetics draws together the different branches of science, unifies them, and stimulates their development. It has given new methods and opened a new approach to extremely important problems. Wiener mentions a number of scientists, among them our own Soviet scientists, who were considerably influential in propounding the concept of cybernetics: U. Gibbs, I. P. Pavlov, A. N. Kolmogorov, and K. Shannon [Shannon]. It should be mentioned that the Russian and Soviet school of mathematicians and engineers have, through their works, created the basis for a science which deals with the general principles of control, many having carried out their work before Wiener. We have in mind the honorable member of the Petersburg Academy of Sciences, I. A. Vyshnegradskiy, one of the founders of the theory of automatic control, Academician A. M. Lyapunov, who invented a strict theory of the stability of equilibrium and motion in mechanical systems, Academician A. A. Andronov, who solved some of the most important problems in automatic control theory, the talented Soviet scientist B. V. Bulgakov, and many others.

At present, a considerable number of Soviet scientists are working with success in the fields of cybernetics, information theory, the general theory of relativity, the theory of control and regulation, automation theory, and also, on the design and development of modern electronic computers, control devices, information [i.e. machines for storing information] and other specialized machines.

Economics, biology, physiology, psychology, and logic are being introduced to work out problems in cybernetics. We have

numerous youth groups being especially trained for work in cybernetics. It is immediately necessary to take all measures to strengthen our Soviet school of cybernetics and to more widely introduce advanced methods of control into the national economy. In a socialistic society which carries on a planned economy, favorable conditions are guaranteed for completely utilizing, for the national good, all the advantages opened by cybernetics, being based on electronic control. It is possible to divide cybernetics into three main divisions, separating them into three main trends of research: theoretical, technical, and applied cybernetics.

Theoretical (or abstract) cybernetics embraces the philosophical problems of cybernetics, and also, its mathematical and logical bases.

Technical cybernetics deals with concrete technical means and systems of means used in control devices.

Applied cybernetics is concerned with the application of theoretical principles and technical means of cybernetics to the solution of problems of control in different branches of human activity (production, power supply, transportation, communication). The field of practical application of cybernetics is constantly broadening. Presently, the possibility is being studied for its application in economy and in the planning activities of different branches of the national economy: finance, supply, accounting, statistics, etc. Processing the wide experience of the medical service of the population with the aid of modern electronic machines opens new vistas for the Soviet public health services. The first, very promising practical results in the field of diagnostics have already been received.

Of course, the above division is somewhat conditional and sharp boundaries between the named fields of cybernetics cannot be drawn. Nonetheless, the main tendencies in the development of cybernetics, with such classification, are separated quite distinctly. Such is the case with any classification. In this case, in theoretical cybernetics, it is possible to also separate concrete, practical problems; and in technical cybernetics, there is a theoretical phase just as there is in any field of the practical application of cybernetics.

#### CYBERNETICS AND PHILOSOPHY

As the case is at times, many of the useful thoughts, ideas and generalizations, set forth by N. Wiener in his book "Cybernetics, or Control and Communication in Animal and Machine" (published in the United States of America in 1948 and available to us [the Soviet Union] in translation not until 1958), were presented with unclear, and sometimes erroneous, ideological and philosophical positions. An unhealthy furor arose over Wiener's idea. The western press made great efforts to debase and give a distorted view of the extremely

deep and valuable considerations of the author of "Cybernetics". This created wariness and distrust of him on the part of some circles of the Russian intelligentsia. It is regrettably true that the period of establishing a rational attitude toward cybernetics was so delayed that it did our science and technology undoubtable harm. We should learn a well-deserved lesson from this, because it may be expected that, in the future, many useful ideas which are worthy of consideration may come to us in similar ideological guise.

At the present time, the enthusiasts and extremes, characteristic, but excessive for ardent followers of cybernetics and its ill-wishers and antagonists alike, are gradually being overcome, and the facts are acquiring their proper perspective. Both skepticism in the evaluation of cybernetics and attempts by some enthusiastic scientists, engineers, and writers to present cybernetics as the equivalent of a philosophical theory and to spread its influence over the whole field of knowledge is absolutely without prospect, and hopeless.

Of course, cybernetics has its philosophical problems just as mathematics, physics, and biology have, but it is deeply erroneous to regard cybernetics as some philosophical theory capable of replacing dialectic materialism. Dialectic materialism is a science which deals with the more general laws of the development of nature, human society, and thought. The main feature of the philosophy is that it is a world view. A world view (*Weltanschauung*) sets before itself the problem of giving people a general view of the world around them and answers the questions: What is the world?; Does it exist eternally, or does it give rise first to one form then another?; Does it remain unchanged, or is it constantly developing and changing?; What place in it do mankind and human society occupy? The problem of the relationship of human consciousness to existence, spirit to matter - of that which is fundamental, primordial - surrounding nature: Is it matter, or just thought, spirit, reason, or ideas? - this is the main problem of philosophy as a world view. These are all well-known truths; however, it is already apparent from this general characteristic of philosophy that cybernetics so differs in that it is incommensurable in the object of its study, the problem set before it, and in the breadth of its generalizations. Although cybernetics deals with complex developing processes, it investigates them only from the point of view of the mechanism of control. The energy relationships, and the economic, aesthetic, and social aspect of the phenomena which occur are of no interest to cybernetics. The interrelation of controlling and controlled systems are studied in cybernetics only in as far as they permit a formal expression with the means of mathematics and logic. Herein lies the problem of working out recommendations, according to the best ways and methods of control, for the quickest accomplishment of a set goal.

Although cybernetics is based on wide generalizations which are correct for all control systems, it has a scientific basis that is incommensurably more narrow than philosophy. Cybernetics has no type of principles which purport to replace or substitute materialistic philosophy. The posing of the problem on this wise is, in itself, illegal. Dialectic materialism studies all of the processes of development in all their varied forms, from the most general epistemological positions. Cybernetics studies, first of all, the utilitarian aspect of control processes for the purpose of increasing the effectiveness of man's activity in this field.

It is true that cybernetics was conceived as a science which would accomplish the synthesis of a whole series of scientific disciplines. The springing up of new sciences in the junctions between different branches of knowledge is, probably, one of the characteristic peculiarities of modern scientific development. In this manner arose biophysics, biochemistry, physical chemistry, radiation chemistry, and many other disciplines which are, in a true sense, unifying subjects of different sciences. Apparently, cybernetics is not unique in this respect. The uniqueness here is that cybernetics grew out of a junction between, it would seem, quite unrelated sciences: mathematics, engineering and biological disciplines. The nature of such a synthesis must surely be of interest in the epistemological considerations of dialectical materialism.

The philosophical problems of cybernetics are connected with explaining the place of this discipline in the system of sciences concerned with nature and society, and the role of modern technology in the development of this discipline; and also, with explaining the role that cybernetics is expected to play in the development of modern science and technology, in the building of a communistic society. To the philosophical problems also belong some methodological problems particularly connected with the application of the methods of mathematics and logic in cybernetics, on the one hand, and experimental methods, on the other; a dialectic materialistic analysis of the essence of the fundamental concepts of cybernetics, as, for example, the concept of "control system", "information", and other concepts, would be a critique of idealistic misinterpretations in the field of cybernetics, the development of which actually takes place in relationship to the principles of dialectic materialism: philosophical conclusions, in this event, would particularly touch upon the relationship of causality and expediency, chance and necessity, entropy and self-discipline, and other quite general categories.

#### SOME FEATURES OF OUR TECHNICAL DEVELOPMENT

The overall development and introduction of a new technology based on the maximum utilization of all the gains and accomplishments of human knowledge takes on a special significance in the

present Seven-year Plan - a very important stage in solving the basic economic problem of the USSR. In the economic competition of the two systems - the socialistic and the capitalistic - that system which, in the final analysis, is leading world progress, and particularly scientific and technical progress, will conquer. The June Plenum of the Central Committee of the Communist Party in 1959 gave concrete expression to the problems proposed at the Twenty-First Congress of the Communist Party with respect to creating a material and technical basis of communism and introducing a new technology into the national economy; and settled the attention of Party and Soviet organizations on the immediate liquidation of all enterprises which were interfering with technical progress. Science is being summoned to play an important role in the contest for technical progress, and for the furthest increase in the productivity of labor.

The principal means to technical progress is overall mechanization and automation of industrial processes. Along with this, increased productivity and improved working conditions can only be attained by the mechanization and automation of industry presupposes the realization of a number of factors whose sum total characterizes the level of technical progress. N. S. Khrushchev has stated more than once that, with the appearance of a new technology, the man upon whose shoulders lay the great responsibility of its utilization will stand in first place [i.e. those responsible for its utilization will acquire favorable status]. Technical refinements are of use only when they are controlled by individuals with purpose - persons who are prepared, well-informed, clever, and capable of guaranteeing the necessary conditions for the successful operation of their enterprises.

The role of automation leads to the partial replacement of manual labor, but the end effect from applying a new technology and automation depends upon how well man knows how to use it. Even cybernetics, which deals with the problem of increasing the effectiveness of human activity, in those cases when it is required to effect a control, by no means excludes man with his knowledges, capabilities, imagination, emotional experiences, and motives. By using the methods of cybernetics and the means of automatic electronic machines, he acquires the possibility of better control. Man creates and directs the new technology toward the solution of problems pertinent to him by ways and means which he chooses by his own discretion. In this case, however, the role of man changes: he expends less physical energy and, in great measure, everything is controlled by processes carried out by systems of mechanisms and automatic machines. The new technology increases the effectiveness of human activity; and mechanisms and automatic devices serve man, and not vice versa. Unfortunately, upon studying and evaluating the social results of automation, some sociologists and economists have inadequately considered this

fact. Our sociologists have still not taken upon themselves the task of creating the capital and, presently, very urgent functions of determining the most suitable ways of developing Soviet economy under conditions created by the transition from socialism to communism.

So, on the complex and difficult way to progress in science and technology, man stands in the lead. Man himself must solve the organizational problem. By properly placing people and expedient organization of work, much may be accomplished without a technical revolution. No type of new technology or automation is effective in the hands of illiterate and not well-informed people, who are, in addition, working under conditions of poor organization.

The procedure of the process stands third. It is possible to utilize a new technology with the necessary effect only with a well thought-out and expedient procedure of production. The new technology itself may essentially improve the procedure. In this case, the organization of production and technology are closely connected.

The mechanization of labor stands in fourth place. A new technology is incompatible with the use of heavy and non-productive manual, non-mechanized labor. Even in 1920, under conditions of post-war ruin, V. I. Lenin, attaching much importance to peat in easing the acute fuel shortage, did not consider it possible to develop a wide program of peat mining because of the extremely heavy labor conditions in the peat refineries. In his report to the Eighth All-Union Congress of Soviets, V. I. Lenin said: "... We have boundless peat resources. But we cannot utilize them because we may not send people to this back-breaking labor ... Under the capitalistic government, people went there to work out of hunger, but under a communistic government, we may not send people to these severe tasks... The introduction of more machines everywhere is necessary, and also, the transition to the use of a machine technology as far as possible" (Works, vol. 31, p. 478). In keeping with the humane and noble purposes of our Party, the liquidation of heavy manual labor in industry, building, in transportation, and in agriculture, on the basis of the overall mechanization of industrial processes, is the most important problem to be solved by the decisions of the Twenty-First Party Congress and the June Plenum of the Central Committee.

Any type of labor mechanization, or the utilization of machines in any industrial process, is unthinkable without corresponding sources of power. Therefore, the following link in the chain of factors which promote technical progress is to provide labor with a power supply. In this event, the supplying of electric power takes on special significance. N. S. Khrushchev more than once has pointed out this requirement, particularly in his speech to the All-Union Conference on Power Building, 28 November 1959: "Without electrification there can be no mechanization or automation of industry. And without mechanization and

automation there can be no growth in the productivity of labor. In order to increase the mechanization of work and raise the productivity of labor, electrification must be realized on a still broader scale. The electrification and mechanization of every branch of the national economy is necessary. This will guarantee a continuous growth in the productivity of labor, by which, in the shortest possible period, we may overtake and surpass the most advanced capitalistic countries in this important factor".

On this wise, along the complex sequence - labor efficiency, organization, technology, mechanization, power supply - follows a new link-labor automation. In case of a break in this chain, i.e. incomplete realization of the preceding factors, automation does not help. Successful realization of automation presupposes high work efficiency, complete organization and technology in industry, a high level of mechanization, and power supply. In this respect, it is necessary to regard automation as the highest degree of mechanization, understanding that the development of the latter up to an overall degree should not so much accompany automation as precede it, and that the realization of complete mechanization of industrial processes in various branches of the national economy still remains the major problem.

Complete mechanization and automation of industrial processes is the key to the solution of basic problems concomitant to the furthest development of the economics of our country and the problems of the Seven-Year Plan: maximum winning of time in the competition with capitalism, a substantial rise in production, and the growth in labor productivity and the living standards of the nation. Only by introducing complete mechanization and automation is it possible to develop the most progressive and recent branches of industry, in particular, chemistry, atomic energy production, electronics, ultrahigh voltages, and other branches which demand quick acting, special accuracy, and which do not permit the direct participation of man in the productive process. In a still greater degree, this belongs to those branches of industry which present working conditions which are harmful and dangerous to life.

The introduction of automation plays a decisive role because, being an expression of the most progressive organization of production, it demands a correspondingly high degree of development in the whole complex of the new technology. To a no lesser degree, the introduction of automation on the highest technical and organizational basis is necessary; and because, under the conditions of socialism, it carries with it the major improvement of conditions and a change in the nature of labor for the workers, it facilitates the effacement of differences between physical and mental labor and effects a cardinal change in the idea of vocations. Upon shifting the work of machines to automatic devices, engineers and technicians will take over the machines and production lines and scientists will be enlisted to control

the more complex productive processes. A machine with program control will function better and more effectively as it receives more logical and more skilled commands from man. In creating conditions for increased efficiency in the technical level of the worker, automation demands, along with this, high qualifications and a serious knowledge of mathematics, electronics, physics, mechanics, and economics on the part of the worker.

Mechanization and automation are not temporal and accidental phenomena, but natural and logical developments of the technology and industry of the present day. They characterize the technical level of the country, guarantee the economy of socialized labor, and subsequently, lower the cost of production.

Automation allows one to consider productive processes as an integrated, unified, flowing system, beginning with the putting in of raw material and ending with the complete manufacture of articles. It should be remembered that it is only possible to automate a highly modern technical process; and that it would be nonsense to automate the old technology, and old machines and techniques. Automation, "superfluous" to the old technology, has no effect. Such automation is not needed by anyone - it is unreliable. It is quite regrettable that there are some people who do not understand this, and much effort and means must be used in combatting such practice. In fits of enthusiasm, such "amateurs of automation" combine the new technological means with the old technical methods. The Central Committee of the Party has more than once pointed out the inadmissibility and fallaciousness of such "introduction" of automation.

Automation may be based on the use of mechanical, pneumatic, hydraulic, magnetic, electrical and electronic devices. The latter exhibit singularly high sensitivity, stability, and adaptability to different working conditions; give off strong signals; and permit remote reception and transmission of information, etc. Automatic electronic machines stand at the end and conclude the above-described chain of factors. It is especially necessary to take this requirement into account when considering the possibility and prospects of using automatic electronic devices. To feel that it is possible to successfully use the devices, means, and methods of automatic electronic devices without preliminary, careful analysis, and without the assurance of all the necessary conditions for such automation, is grossly erroneous.

In our day, a new branch of electronic automation - electronic computers and control devices - takes on new meaning. The conditions under which these machines will be of use are still more complex than those under which the standard automatic machines were used. A control device raises especially strict requirements for quality in the technology and organization of production. Moreover, with good organization and a high level of technology, electronic control devices can have a most

productive and economic effect. In particular, they are capable of operating on a program such that the continuous solution of problems arising during the production process is carried out in the most suitable manner. In other words, these devices are capable of establishing and maintaining optimum operating conditions for some process or other. In this respect, they do more than any other device in electronic automation, even more than man.

At the present time, we have a great opportunity in the use of quick-acting electronic machines to solve one of the most important organizational problems - the problem of control. Of course, the question is not one of control by the simplest procedures. In actual practice, we are often confronted with quite complex developing problems which are a combination of many interconnected simpler problems. In every case where a concrete purpose for the development of a process can be determined, the problem of control arises. Its solution is far from trivial. Cybernetics, as a science which embraces control by complex dynamic processes, first of all permits the presentation of this problem, in its general form, on a scientific basis, and formulates it into the language of an exact science. In contrast to the earlier existing elementary and empirical methods of solving the problem of control, the possibility of finding strictly scientific methods for its solution now exists.

#### AN IMPORTANT PROBLEM OF TECHNICAL CYBERNETICS

Modern development presents cybernetics with a great number of varied problems which demand solution. In accordance with a resolution by the Presidium of the Soviet Academy of Sciences, in 1959 the Scientific Council on Cybernetics was created at the Academy. At the present time, the Council has prepared extensive recommendations on basic problems of cybernetics, and on the direction and coordination of scientific research in this field carried on in the Soviet Union. From the whole gamut of problems in cybernetics, we should like to turn out attention to one that is most directly related to the successful introduction of automation into the national economy of the country. I have in mind the reliability of control.

The point is, that, as the procedure and utilization of a large number of interconnected parts and units in some system or other become more complex, a very serious problem arises as to the reliability of the operation of such a system as a whole. Generally speaking, this problem concerns a whole new branch of technology, but an especially acute problem ( and the reason is understandable) exists in the application of automatic electronic means, and particularly, electronic control devices. Actually, electronic computers carry out the solution of some problems up to ten million times, but the general number of elementary operations

is of the order of  $10^{10}$ . If, due to a technical defect, some elementary act is incorrectly carried out, for example, if somewhere an impulse is not transmitted, then the final result may also appear untrue. The prevention of all possible defects in a system composed of tens and even hundreds of thousands of working elements and millions of contacts, junctions, and connections is a problem of unusual difficulty. For this reason, the reliability of an automatic system must be studied with special care. Our present difficulties in introducing automation in production are not only connected with the lag in mechanization, but also with the lack of instruments, apparatus, and the means for automation; and the available instruments and means are, in themselves, insufficiently reliable in performance, and unsuitable for application in responsible operations.

Complex production processes are attended by highly qualified workers and technicians, masters of their craft, who have much experience. They quickly react to a changing situation and almost automatically find a problem of control by a professional process. These people are very reliable, and, in most cases, one can depend upon them. However, such general characteristics seem extremely vague and totally insufficient when a problem arises concerning the replacement of qualified workers by automatic devices in the function of production control. Automatic devices must not only work faster and more accurately than man, but also, more reliable. Obviously, all the productive and economic benefits derived from the use of such automatic devices may be instantaneously lost as soon as the device gets out of order. And if a distorted telephone message or telegram may be repeated several times, the repetition of the incorrectly given or transmitted command by the control is needless. The results may not only be loss of time and damage to material, but also serious accidents involving human lives and great losses to the national economy. It is quite clear, that automatic devices must be no less reliable, and in many cases more reliable, than the man whom they replace.

In order to compare the reliability of the work of an automatic device with that of man, it is necessary to set up some criteria for this reliability; study cases, reasons, and conditions under which man begins to work reliably; and determine the permissible limit of reliability in his work. It should be stated that our studies of the reliability of the work of man under various conditions, in different production circumstances, and at different stages of fatigue have been totally insufficient. The author, in spite of enterprising efforts, was not able to collect such material. And surely, in our country there are more than one hundred thousand railroad switchmen, tens of thousands of telephone operators who serve long-distance and manually operated city telephone stations, a considerable number of

clerical workers, in essence, carry out quite simple, repetitious, computing operations; hundreds of thousands of drivers, and the bulk of doctors in diagnosing, use machine control. How many errors are made in these cases; what is their probability; and what will they cost us? At the present time, we have no such data.

We have set before ourselves the problem of increasing the productivity of labor, and we are even planning such an increase. This is actually one of the most important problems. And for this reason, the productivity of labor is being studied, although with extremely crude methods. Why then, isn't the reliability of man's work studied? Sociologists, psychologists, and economists, by considering this problem, could be of great benefit both to themselves and to business. Absolutely reliable mechanisms, not to mention automatic devices, are not extant. Consequently, one must turn to the well-known compromise. What are the permissible limits of risk? Apparently, not having data on the reliability of man's work, we are not able to determine the possible reliability of the work of an automatic device.

In creating electronic machines, man learns from nature just as he learned from it in creating equipment for physical work. However, the brain is infinitely more complex than the hand or foot, and modeling the brain is only the first step. Still, [the simulation] of many of the brain's characteristics is an unobtainable ideal. One of these is its ability to do reliable work, with great resourcefulness, and with a negligible expenditure of energy, in spite of its small size and weight. In the small capacity of the brain, there is a concentrated system composed of 10 - 15 billion super-miniature, light, and reliably functioning neuron cells which put out a billionth of a watt [of electrical current] per each neuron. Even our dreams of super-miniaturizing control device components is extremely short of that attained by nature over millions of years of natural selection and the struggle for existence.

In the brain there are no cells similar to the different condensers, inductors and resistors, and no vacuum. The brain consists of complex organic protein substances which form a nerve tissue. The brain requires 20 times more oxygen than muscle fibers (per unit weight). The main source of energy for the brain tissue is carbohydrates, especially glucose, of which it requires twice as much as muscle fiber. In the covering of the large hemispherical cerebrum [i.e. the cerebral cortex], which has an overall thickness of 2 - 5 mm in man, the main centers of higher nervous activity are located; and there, physiological processes - stimulation and relaxation - take place. These processes are connected with the existence of [biocurrents] which may be located, amplified, and analyzed. Although our knowledge of the structure, compositions, and functions of the brain are extremely insufficient at the present time, and often, they are

conjectures; and that that we do know compels one to be astonished at the uniqueness of its structure.

Nevertheless, the brain works slowly, and this does not suit man. The brain has an insufficient memory and is capable of forgetting the necessary. It is very fragile, will not withstand concussions and blows at all, and it is subject to various pathological changes. In transferring the simplest functions to electronic machines, man "corrects" some of the brain's defects. The main thing gained in this respect is quick-action. However, in comparison with the brain, the existing machines have considerable defects: they work unreliably and frequently require many checking operations.

This thought occurs: Is it possible, after all, to model only that part of the brain in which there is some definite relationship? Is it possible, for example, to use in technology elementary systems which simultaneously exhibit capacitance, inductance, and resistance, and which have these parameters in the necessary relationship? Or perhaps, to succeed in general means to manage without these elements? Or maybe it is possible to use monolithic blocks of materials, each of which will fulfill some definite function of a point in a radio-electronics device? It should be stated that such a field of electronics - molecular electronics, or moletronics - has already achieved some development. The problem of molecular electronics is to create a molecular structure of substances which would guarantee those properties necessary for controlling a flow of charged particles with the aim of accomplishing given results. For this purpose, ultra pure semiconductor crystals are used, which are so processed that they contain small quantities of the necessary chemical impurities and structural anomalies. In this case, electron spins, fields, etc., function as capacitors, inductors, and condensers.

Several foreign [non-Soviet] firms are carrying on considerable work in this direction. Functional points of [radio-electronic] devices, in the form of germanium blocks, have been created, i.e., slight telemetric amplification of capacities of  $0.015 \text{ cm}^3$ , utilizing one component as opposed to fourteen in the standard amplifier in transistors; and a generator with a frequency of repeated impulses in ranges of from 10 to 100 kc and with duration of impulses up to 1 micron/sec. By depositing, pickling, and diffusion, diodes, transistors, resistors, and capacitors have been made from one piece of silicon. By these methods of creating "monolithic circuits", multivibrators and heterodynes with phase shift have already been developed.

Similar projects are still in the initial stage, but they deserve the most earnest attention because their aim is to increase the reliability of the work of a system, to lower losses due to power leakage, and to increase the number of functional points

per unit volume ( which allows considerable saving of space). I shall dwell upon other projects and ideas in the field of super-miniaturization, but I shall mention, however, that they can open a new era in radio-electronics. It is necessary for us to expand research in this direction without delay, enlisting the support of the most qualified chemists, metallurgists, physicists, crystallographers, radio operators, and technicians. In this connection, in particular, it is necessary to significantly improve and advance work in the field of semiconductors.

The problem of increasing the reliability of the work of automatic devices has several aspects, and its solution is being sought in different directions, both by way of modernizing the available technical means, producing more reliable components, and also, by way of improving the arrangement of component parts of machines. In particular, electron and vacuum tubes are being replaced by transistors and ferrites, because machines operating on ferrite components are considerably more reliable. For example, in the universal digital computer of the Laboratory of Electromodeling of the Soviet Academy of Sciences, the average monthly loss in component failures is 0.1% of their overall number, as opposed to 6% in other machines.

The results of J. von Nieman, who has demonstrated the possibility of constructing a reliable automatic device from unreliable components by means of an improved arrangement of its parts, are of prime importance. Nieman studied the necessary organization of certain switching organs which showed some constant probability of error in order to possibly synthesize from them a reliably functioning automatic device. An abstract theory of automatic devices, recently developed on the basis of mathematical logic, deals with a complex of problems of this type. Of results obtained here recently, we should like to point out the work of mathematicians of Moscow State University, who have synthesized a contact relay circuit, without duplicating components, which is not disrupted by short circuit.

In conclusion, let us emphasize once more that the problem of insuring high reliability of the work of automatic apparatus is developing into a problem of first degree importance. Without its solution, no major advancements in the development of automation can be made.

In seeking out new methods of increasing the reliability of the work of apparatus, and in particular, the problem of their miniaturization, it is necessary to turn to the development of a concentrated, long-range research project, uniting the forces of different specialists by creating a scientific research institute on reliability at one of the large companies. It is necessary that the State Planning Committees of the USSR should plan to improve reliability just as they are planning to increase the productivity of labor and to introduce a new technology.