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PROGNOSIS OF THE STATE OF HEALTH OF A PERSON UNDER SPACEFLIGHT CONDITIONS

anonymous

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16. Abstract

One of the most important basic tasks of predicting we consider to be the development of methods of prediction in relation to the specific individual. The diversity in types and pronounced nature of reactions to the same conditions, even among a comparatively uniform contingent is very great. The development of extrapolation methods of prediction requires a justified isolation of the more informative physiological indices and their combinations for this purpose. Ground prediction will, apparently, develop along the path of harmonic combination of heuristic and formal procedures.

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PREDICTING THE STATE OF HUMAN HEALTH IN SPACE FLIGHT

Introduction

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The task of predicting the state of health and of human efficiency during a space flight continues to remain one of the most intriguing and practically important problems in modern science. The results of the space expeditions [1-3] which have been made up to now provide the basis for the assumption that the need to predict the dynamic processes in the human organism stimulates research which will have not only applied, but also general biological importance. On the other hand, formulation of reliable and pithy procedures of prediction will to a specific degree be useful for clinical medicine also. It is difficult to overestimate the importance of predicting the human state and related reliability as elements of a single biotechnical system in planning and predicting the development of new space resources. Convincing examples of this are contained in the chief study of NASA [4]. Finally, active control over the conditions of crew members is not possible without a prediction of this condition.

In the previous reports of the Soviet delegation to the meetings of the working group on space medicine and biology, the results were presented from work on prediction with the help of extrapolation algorithms and on the mathematical aspects of expert predicting. Currently, work is being done to integrate various methods and algorithms of prediction within a single system. A number of aspects of this work are treated in this report. We considered it appropriate to finish the report with a discussion of certain unsolved problems which have, in our opinion, great importance, and of perspectives for developing the system.

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*Numbers in the margin indicate pagination in the original foreign text.

I. General Structure of the Prediction System /4

As indicated in report [7], one can currently isolate three main directions in predicting the human condition under extreme conditions using mathematical algorithms and computer technology: expert prediction, prediction with the help of extrapolation algorithms and the use of simulation models. Despite the definite favorable results achieved with the use of these methods, each of them has specific limitations. Corresponding questions were treated in great detail in reports [5, 6, 7]. Nevertheless, it is appropriate to briefly treat their characteristics once more.

The use of expert prediction makes it possible to make very complete use of the intuition and knowledge of highly qualified experts. The method produces the most satisfactory results with prediction of signs of an intergral nature. The prediction of the course of change in a number of physiological parameters which have a real quantitative and measurable expression is less positively implemented. In the deficiencies of the method one should include the need for attracting a fairly large group of highly qualified experts not only for the period of operational work, but for the preliminary training which would permit elimination of obstacles associated with the self- instruction of the group of experts and the dynamics of intragroup relations. On the whole it appears that today it is expedient to use the method of expert prediction by supplementing it with certain mathematical procedures of prediction of which we will now speak.

By prediction with the help of extrapolation algorithms we mean the vast group of prediction algorithms which employ the methods of extrapolation of temporary progressions. In report [5] and earlier reports the results are given from predicting the pulse rate of cosmonauts with the help of nonlinear discrete /5
filters, with the help of regression equations whose coefficients were dynamically evaluated with the Kolman-Byusi algorithm or the method of stochastic approximation, as well as with the help of a linear differential equation whose coefficients were evaluated according to the available a priori information. One can arbitrarily include in this group of methods the algorithm for analyzing the status of the cardiovascular system with the help of moments of sampling

distribution of intervals RR and certain other techniques for which it is common that prediction of the change in certain physiological indices is made on the basis of the available a priori information with the help of formal mathematical algorithms. A description and the results from using a number of these algorithms are contained in article [8]. The mechanism for adaptation and the possible pathogenesis of physiological systems under new conditions is clearly not taken into consideration in the course of prediction. The potentialities and limits of applicability of this group of methods for prediction are not yet completely clear, however there is basis for the assumption that they are fairly limited.

Finally, the third of the aforementioned directions is simulated modeling. The American concepts of this direction were presented at the meeting in report [6]. The Soviet side stated its view in reports [7] and [9]. The next sections of this report will give a fairly detailed treatment of the problems related to simulated models. Therefore, without going into a detailed discussion here we note the great hopes which we hold for the given direction. However, it requires development and can hardly be viewed at present as a method capable of replacing all the others.

Thus, it is expedient to solve the problem of prediction at present by a combined use, approbation, modification and perfection of the methods of all the aforementioned directions. /6

The task of controlling the human state under extreme conditions is essentially a task of situation control, the principles of which are presented in [10, 11]. Situation control is a new branch of operational study which is designed to study the behavior and synthesis of organizational systems which are realized with the help of man-machine complexes. The strategy of behavior of the organizational systems on the whole emerges as an intercorrelated system of strategies of all its hierarchical links. In the scope of this work we will not touch upon the interesting problems of classifying situations, adopting solutions and corrections for the current and future condition of crew members and will limit ourselves to the task of evaluating and predicting. The general structure

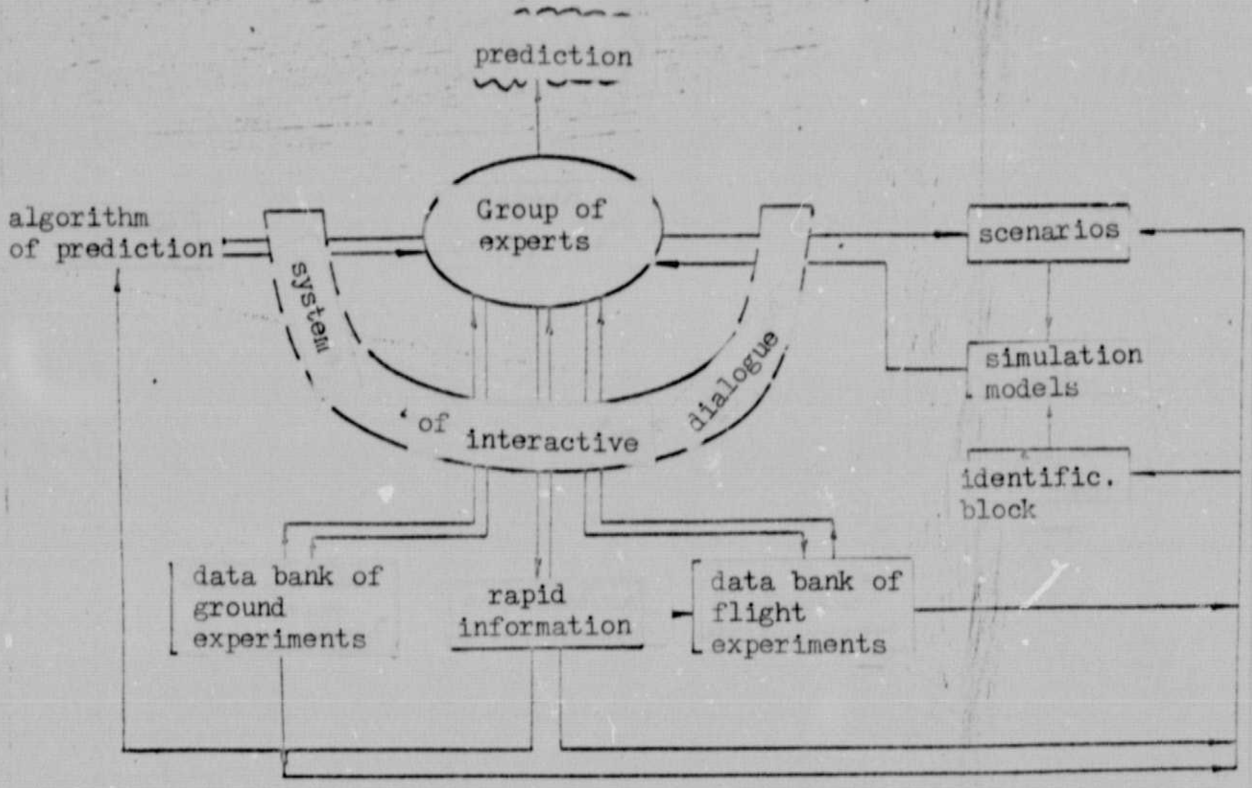

Figure 1. Schematic Diagram of General Structure of Prediction System.

of the currently accepted prediction system is schematically depicted in fig. 1.

The central role, as is apparent from the presented scheme, belongs to the group of experts which also formulates a final judgment for further use in the general system of flight control. In the process of work the experts employ both the operational information coming in during the flight and the information stored in the data banks which contain information on the past flight as well as ground experiments. The sampling and formation of data files, their correlation and comparison with the help of statistical algorithms, as well as other necessary operations are conducted by a system of interactive dialogue.

A peculiarity of the dialogue system developed in the IMBP [Institute of

Med.and Bio.Prob.] is that it can be used by an individual who does not have special mathematical knowledge, such as the overwhelming majority of experts, and with data bases in the interactive pattern founded on a language of fairly low level. On the other hand, it was necessary to ensure the possibility of operational development in the set of procedures for processing data at the /8 suggestion of users by mathematicians and specialists on the basis of developed algorithmic languages. Both requirements were fulfilled by decomposing the system into two program components. The "Dialogue" component ensures dialogue of the user with the computer whose logical structure is a combination of data selection and selection of the method for manipulating them. Interactive dialogue in a language as close as possible to the natural is conducted as desired through display or a printer. The "Monitor" component permits rapid processing of new program modules for the "Dialogue" components. After this the modified "Dialogue" component is copied into the library of absolute modules in place of the previous modification and becomes available to the user. In the structurization of the data base for ground experiments the following were used as attributes: the subject of study, the method of study, moments of registration for each method, parameters of registration for each method and moment, and the formats for presenting the data.

Analysis of rapid information and data stored in banks is supplemented by the use of algorithms of extrapolation prediction and simulation models. In relation to the fact that the technique of working with extrapolation algorithms which was reported in detail at the past meetings has not undergone cardinal changes up to now we will dwell in more detail on the use of simulation models.

As is known, the main difference between the simulation models and the traditional descriptions of the studied system in the form of relationships binding the indices of input and output consists of the fact that with their help complex systems are studied by multiple reproduction on the known structure for the course of the dynamic process with preset starting conditions, external factors and model parameters. In so far as the standard analytical methods of research are effective only with extremely simplified form of models, it is /9 correctly noted in [12] that in simulated modeling instead of exact analysis of approximate models approximate analysis is made of structural-functional models

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which correspond more to reality.

The process of assigning the set of conditions which characterize the specific realization of the dynamic process, by using the existing terminology, we will call assigning the "scenario" for the operation of the simulation model. For simulation modeling in physiology the compilation of the scenario includes presetting the parameters characterizing the statute of the organism of the subject or an individual physiological system, the external conditions (environmental temperature, composition of atmosphere, quantities of consumed water,etc., as well as the possible change in these characteristics over time), and also when there are different hypotheses on the physiological mechanisms, the choice between these hypotheses. The indicated work is an important creative process fulfilled by the user-physiologist in consulting and working with the mathematician. Further, in the mass use of the technique of simulation modeling it will be possible and expedient to automate this procedure to a higher degree.

Simulation models used in predicting are discussed in the next section of the report. We note that rapid information and the results of past experiments are used in simulation modeling in a two-fold way. First, they are employed in developing and assigning the scenarios. Second, they can be used to identify the unkown or inaccurately assigned parameters of models. For this purpose a special block for identifying models of dynamic processes with a finite number of degrees of freedom was formulated.

The purpose of creating this specialized operational system is to ensure /10 ease of operation on a computer by the researchers and to automate the use of rapid information and data bases in work with simulation models. Its development made use of the ideas stated in [13] and [14]. The functional composition of the system is determined by the block diagram in figure 2.

The dynamic systems which can be studied with the help of the system in the existing version ASIM 04 is described by the following system of equations

$$\mathcal{F}_i \{t, x(t), v(t), u(t), \dot{x}(t), a, \lambda(t-\tau)\} = 0 \qquad i = \overline{1,n}$$

$$z = \varphi(x, v, u, t, a)$$

where t--time, x--vector of differential variable states, v--vector of algebraic variable states, u--vector of input factors, a--vector of parameters, z--output matrix, λ--symbolic parameter characterizing the presence of variables with time lagging. It is proposed that there exists a single solution to the system which satisfies the preset starting conditions and the system can be solved relative to v(t) and x(t), i.e., reduced to the system of differential difference equations of the lagging type in the form of Cauchy.

The task of identification consists of determining the unkown components of vectors a and $x_0=x(t_0)$. This problem is solved by minimizing criterion CRID (see scheme 2) which is a measure of deviation for the solution of the system from a certain standard. The methods of Fletcher-Powell or conjugate gradients are used as methods of optimization in the existing variant. The system permits one to find and predict the trajectories of the simulation model. The solution to the system can be found at the preset finite set of time intervals on the condition that for the starting moment of time the starting conditions x_0 are assigned and the values of parameters a.

The quality of the simulation and of prediction depends, naturally, on the accuracy of assigning x_0 and a and in the identification of the system is related to the number of approximations and the convergence of the identification process). In finding and predicting the trajectories of the simulation model the user can select at his discretion one of seven methods for solving the differential, differential-difference and difference equations. The procedures indicated in scheme 2 include the system subprograms DIALOG, IDENT, FUNC, SOLDE, CRAD and the subprograms of the user PRINT, CRID, EQU and OUTP. The system subprograms feed in input information, form files, solve systems of equations, compute values which are minimized in function identification, retrieve the minimum for computation of the adequacy criterion and perform a number of service functions. The user subprograms serve to compute at the present /12

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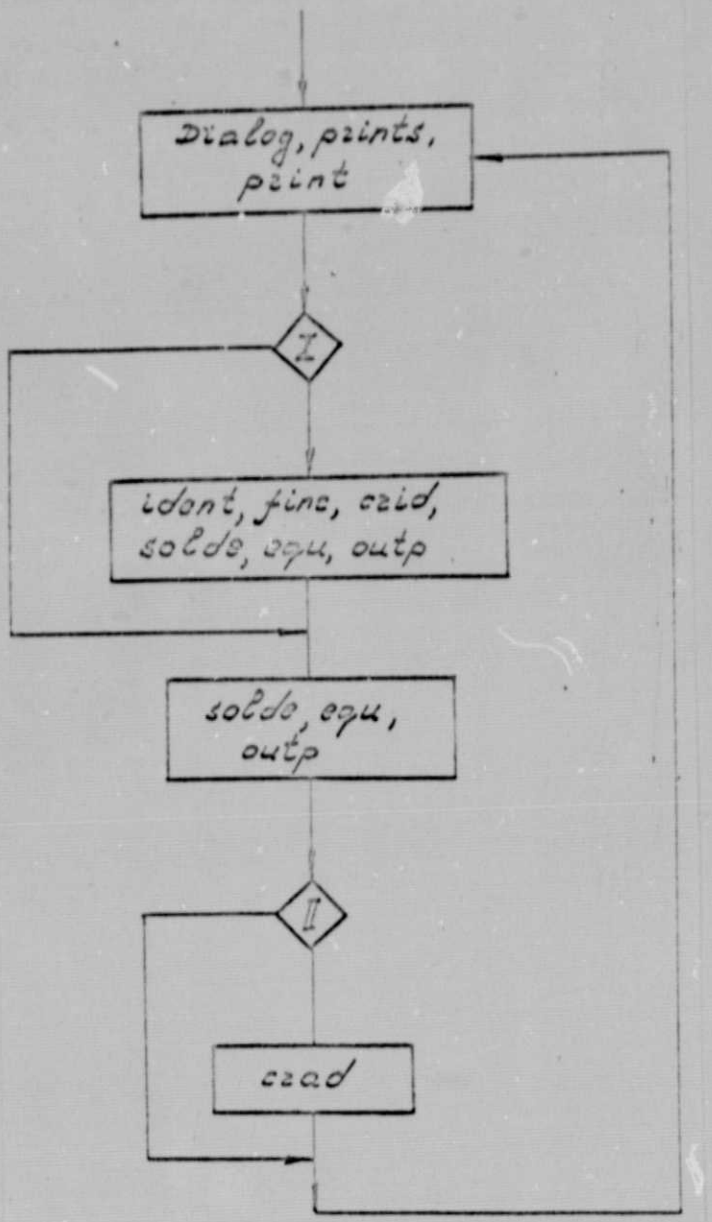

Figure 2. Block Diagram of Identification Block

moment of time the values of derivatives x and variables, to form output matrices, and feed in information differing from the standard. The presence in the system of a component which is "stronger" and variable at the user's desire facilitates work with it, however on the whole it is designed for use by experts either with the help of consultants and mathematicians or in perspective with the help of appropriate expansion of the system of interactive dialogue.

In the existing variant the total number of variables in the system of equations must not exceed 500. The total number of identifiable parameters does not exceed 100. The number of standard points is limited to the number 200 and the number of moments in time for which a solution to the system is computed also equals 200. The identification block is realized in the form of objective models on the ES computer. The overall volume of the memory is 200K of which 140K are reserved for variables and files. Some questions related to the practical use of the identification block are discussed in the next sections of the report.

The structure of the prediction system presented here reflects the current state of this problem. The accumulation of practical experience will result in its definite modification which will mainly consist of changing the priority and and content of individual components of it. /13

II. Simulation Models in Predicting the Human State in Space Flight

Work has been conducted in the Soviet Union over a number of years on simulation of the main physiological systems of the organism. The works of the group of Prof. V. I. Shumakov [15] were a great stimulus in this area. In order to solve special problems of evaluating the human state under experimental conditions in 1976 development was begun of a set of models including models of the cardiovascular, respiratory and renal systems, systems of erythropoiesis and systems of thermoregulation. We further present the main information on the structure and potentialities of each of the models.

In order to describe the processes occurring in the cardiovascular system a circulation model was devised which is a compact analytical interpretation of current information on the main mechanisms for the functioning of this system. A considerable part of the appropriate information has been gathered from works [16] and [17], as well as from the sources cited in them. The block diagram of the model is presented in figure 3.

The model of the cardiovascular system describes the processes of blood circulation in the greater and lesser circles of circulation and permits determination of the amount of cardiac discharge, the pulse rate, as well as the pressure, volumes, flows and resistances of vessles in various sections of the cardiovascualr system, for example, in the basins of head, arms, legs, kidneys, etc. The model autocontrol unit permits consideration of the effects of changes /15 in the sympathetic-parasympathetic balance governed by shifts in the partial pressure of oxygen in the tissues and the amount of arterial pressure which are recorded by chemo- and baroreceptors, and in addition in the intensity of muscle work and blood supply to the central nervous system, on the activity of the cardiac contractions and redistribution of vascular tone, Also taken into consideration are the effects of the action on hemodynamics of the venous pump, intrapleural and intraabdominal pressures which change synchronously with respiration, local tissue control of vascular tone, and a change in the force of gravity. Inputs into the model, such as the dynamics of respiration, volume of blood, partial pressure of oxygen in the arterial blood, are variables computed with the help of models for water-salt exchange and respiration.

The model of the cardiovascular system can operate both by interacting with the aforementioned models and autonomously. In the latter case it becomes possible to analyze the processes in the circulation system which are governed only by hydrodynamic profiles of control, such as the effect of the volume of vessels on the pressure in them, of pressure on resistance to blood flow of the cardiac discharge, and so forth. An illustration of the given thesis is the simulated reaction of the system to an increase in pressure in the auricles which can occur in orthostatic tests and in weightlessness. Figure 4 presents the dynamics of certain variables characterizing the dynamics of circulation and especially of arterial pressure and pressure in the left ventricle, cardiac discharge and the volume of the venous network of the greater circle. The results of the simulation showed that the simulated system in itself has homeostatic properties, compensating for the influences on it. Thus, compensation for an increase in pressure in the left ventricle (its reduction from 7.7 to 2.3 mm Hg) occurs due to the change in volumes of currents and pressures in other parts of the system. The characteristic time of compensation is on the order of seconds. /17

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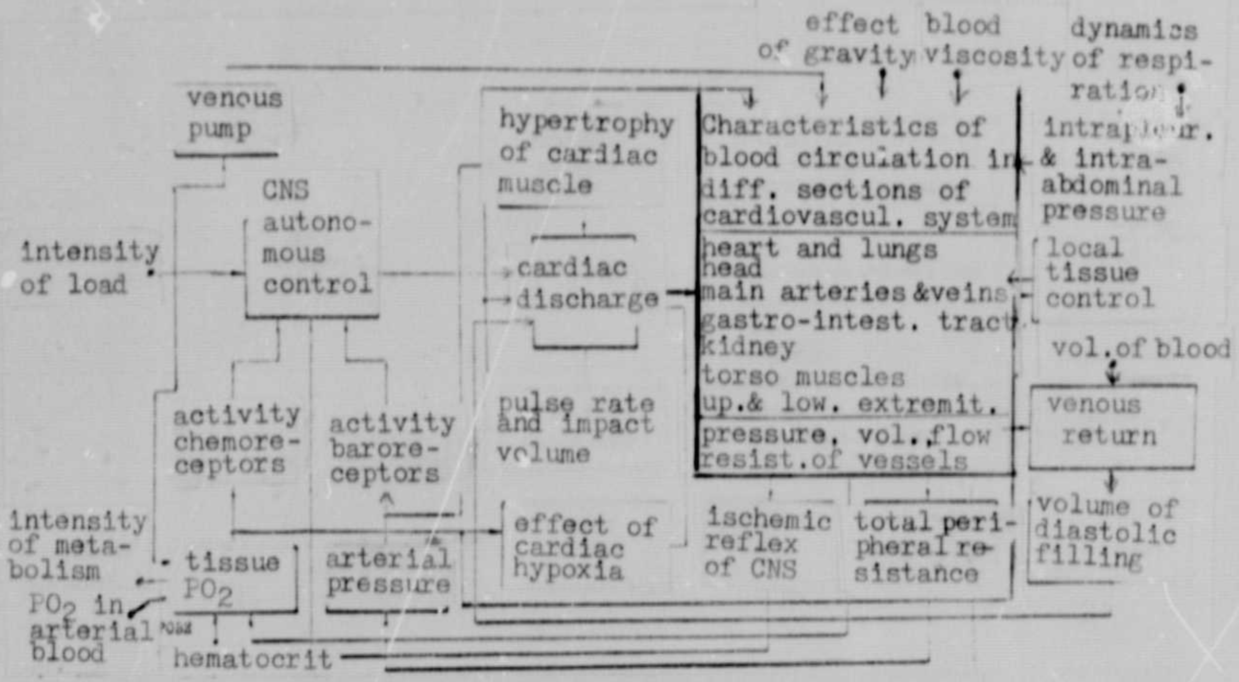

Figure 3. Block-Diagram of Model for Cardiovascular System

The obtained result is important for understanding the mechanisms of the Henry-Hauer reflex which begins with a change in pressure in the left auricle and initiates an entire set of processes observed in zero gravity.

In order to evaluate the effect of long-lasting processes, for example, those such as cardiac hypertropy and others, it is necessary to connect to the model additional blocks which are characterized by large time constants. This also concerns a number of effects which are specific for a long space flight. They include, for example, the effect of decalcification of the organism and a change in the content of electrolytes on the reactivity of the heart and vessels, as well as the effect of a change in the reflex adaptivity of individual vascular basins under conditions of a prolonged absence of gravity forces. A study of these phenomena will be conducted with the help of more complete version of the model which is currently being developed.

One of the main places in the process of human adaptation to prolonged stay under conditions of weightlessness is occupied by the system of water-salt

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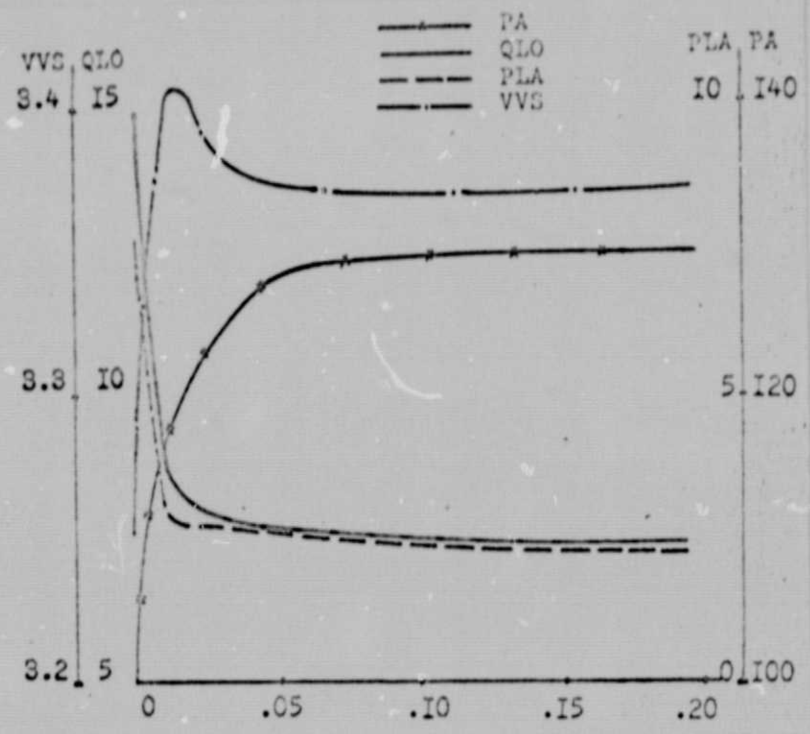

VVS--volume of venous system of greater circle (l);
QLO--discharge from left ventricle (l/min);
PLA--pressure in left auricle (mm Hg);
PA--arterial pressure (mm Hg).

Figure 4. Reaction of Model for Cardiovascular System to an Increase in Pressure in the Auricles.

exchange. Redistribution of the volumes of fluid and establishment of a new equilibrium state in the water-salt exchange are one of the main consequences of zero gravity. However, the indicated equilibrium is relative, as indicated by the process of increased excretion of calcium which can be a factor limiting the duration of the space flight [4].

The formulation of a model for water-salt exchange employed materials on the physiological mechanisms and their modeling contained in [15-20], as well as experimental materials on the reaction of the renal system to the conditions of space flight published in [2, 3, 21-23]. The structure of the model is shown in fig. 5.

In the development of a block for renal hemodynamics and filtering it was expedient to take into consideration the time lag in the chain of regulation of /18 preglomerular resistance by the rate of filtering, to introduce factors which determine in accordance with the instantaneous hypothesis the mechanism of autoregulation which ensures the relative stability of the renal blood flow and the rate of filtering in a fairly broad range of values of arterial pressure (77-120 mm Hg), as well as to introduce a number of other modifications in comparison with the version of the model for this system presented in [16]. The description of the transport of electrolytes takes into consideration the processes of reabsorption and excretion of certain bivalent cations and the interdependence of the transport of sodium, potassium, calcium and magnesium. It is accepted that the absolute amounts of reabsorption of calcium and magnesium are limited, whereby under normal conditions the rates of reabsorption are close to the limit. The first approximation takes into account the effects related to depositing of calcium and its emergence from the depot and the endocrine control of these processes.

The obtained variant for the model permits simulation of a comparatively broad spectrum of phenomena, including the Henry-Hauer effect (jointly with the cardiovascular system model), the reaction of a healthy and functionally weakened organism to water and salt loads under normal and extreme conditions, effects which occur with a varying statute of hormonal control and others. Figure 6 shows the reaction of the model to water-salt loads, qualitatively corresponding to experimental data. In the given case the situation is illustrated in which the control of the sodium concentration, on which the total osmotic concentration of plasma depends, is implemented by rapid mechanisms whose functioning is related to ADH (antidiuretic hormone). The selective control of the ionic composition of plasma is a slower process. Therefore, the calcium load elicits a rapid increase in diuresis and a check of sodium, only after a restoration in the calcium concentration. /20

The series of tasks which were solved with the help of a model of water-

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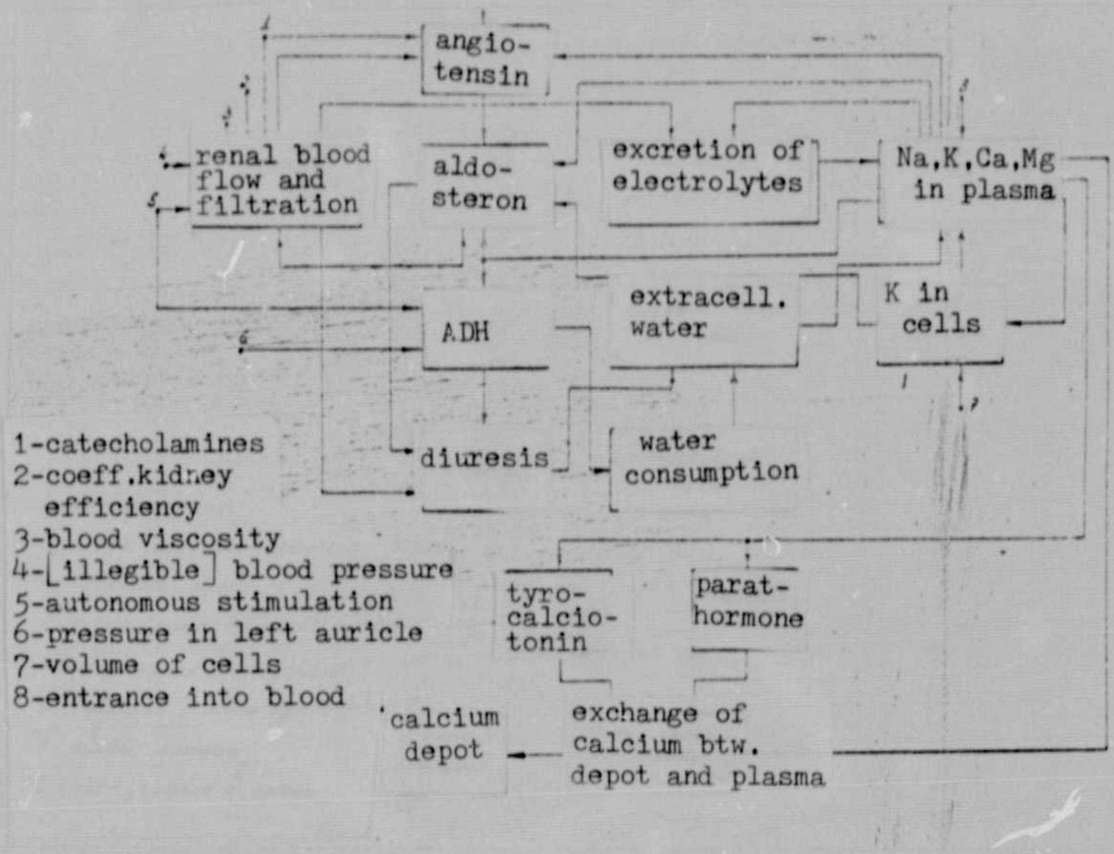


Figure 5. Block Diagram of Model for Water-Salt Exchange

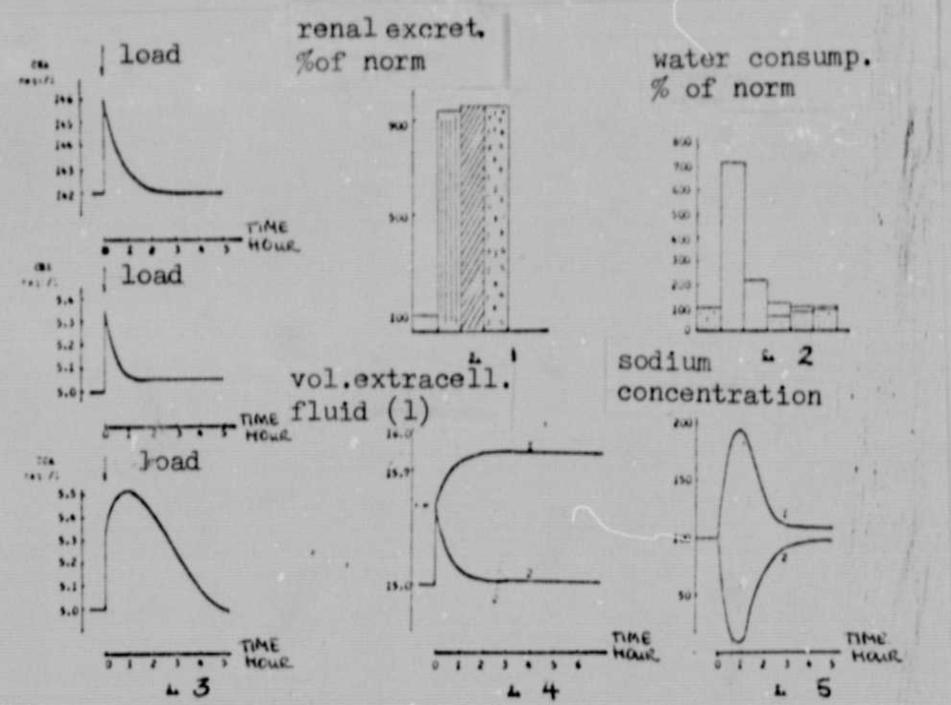
salt exchange mainly included tasks of two types: evaluation of the course of dynamic processes for transport of water and electrolytes and its control for the assigned situation (according to the assigned "scenario") and identification of the unknown and in a number of cases immeasurable parameters for the preset experimental curves with the help of the identification block.

Figure 7 presents the block diagram for the model of the erythropoiesis system based on the generally accepted conclusions presented in [25]. A peculiarity of the model is the calculation of the age structure of the population of erythrocytes circulating in the blood. Calculation of the model for the dependence of functional properties of the erythrocytes on their age permitted simulation of the reaction by red blood to a number of factors, resulting in the selective destruction of individual age groups (for example, the death of reticulocytes in overloads). Calculation of the dependence of the aging rate of erythrocytes on the intensity of metabolism makes it possible to describe the changes in the total number of erythrocytes and the oxygen capacity of blood during changes in the level of physical load. The age distribution $A(t, \tau)$ (t--normal time, τ--biological age) is determined with the help of the equation

$$\frac{\partial A}{\partial t} + D(t)\left\{\frac{\partial A}{\partial \tau} + f(t, \tau) \times A\right\} = 0$$

The synthesis rate of erythropoietin and the rate for the entrance of reticulocytes into the blood are defined by two common differential equations. Figure 8 shows the change in the number of erythrocytes (R) and reticulocytes (RET) and the change in the age distribution of erythrocytes in response to the increase in the rate of constant hemolysis by 50%. The stimuli for erythropoietin synthesis are a reduction in hematocrit and the presence of a signal for oxygen debt. The measure of oxygen debt is the difference between the amount of oxygen necessary for the given level of metabolism and the oxygen capacity of blood. /21
In the analysis of the oxygen capacity of blood the dependence of the oxygen capacity and the level of the natural energy expendidtures of erythrocytes on their age was accepted. The model permits computation at the preset levels of metabolism and the volume of plasma of the quantity of erythrocytes and reticulocytes, hematocrit and oxygen capacity of blood and evaluation of the content of erythropoietin in the blood and a number of other parameters.

With the help of the model simulation was conducted for the reaction of the system to a reduction in the volume of plasma and the intensity of metabolism. As an illustration, figure 9 presents a graph showing the course of restoration in the erythrocyte mass after restoration of the volume of plasma and the level of metabolism. For comparison data are plotted on the graph corresponding to the results of the experiment "Skylab-3" (59-day flight). The test simulation revealed the character of the periodic patterns for the processes in the system even without external periodic perturbations. The periodic nature of the process limits the expediency of using root-mean-square values since in the group there may be individuals with essentially differing values of amplitude, phase and periods of oscillations.



3--restoration of ion compos.of plasma after diff. salt loads,
CMA, CKK, CCA--concent.of sodium, potassium,calcium in plasma
1--Renal excret.in 1 h after ▨ - [illegible] ☐ - [illegible] ▥ - [illegible] ▨ - [illegible] loads
2--changes in consump.water sodium and water loads
4--changes in volume of extracell.fluid after sodium(I) and water (2) loads
5--sodium content in water after sodium (1) and water (2) loads

Figure 6. Reaction of Model for Water/Salt Exchange to Salt and Water Loads

The set of simulation models includes a model of the respiratory system; the block diagram for it is presented in fig. 10.

The respiratory system is viewed as a profile closed to control and consisting of the following links: controlling link represented by a bulbar respiratory center, respiratory muscles of the diaphragm, slowly adapting receptors for stretching of the lungs,and arterial chemoreceptors, and a controlled link including the lesser circle of circulation. The model takes into account the properties of blood as a carrier of oxygen and carbon dioxide and the processes of gases mixing in the bronchial branch.

An important factor is the allowance for the influence upon the

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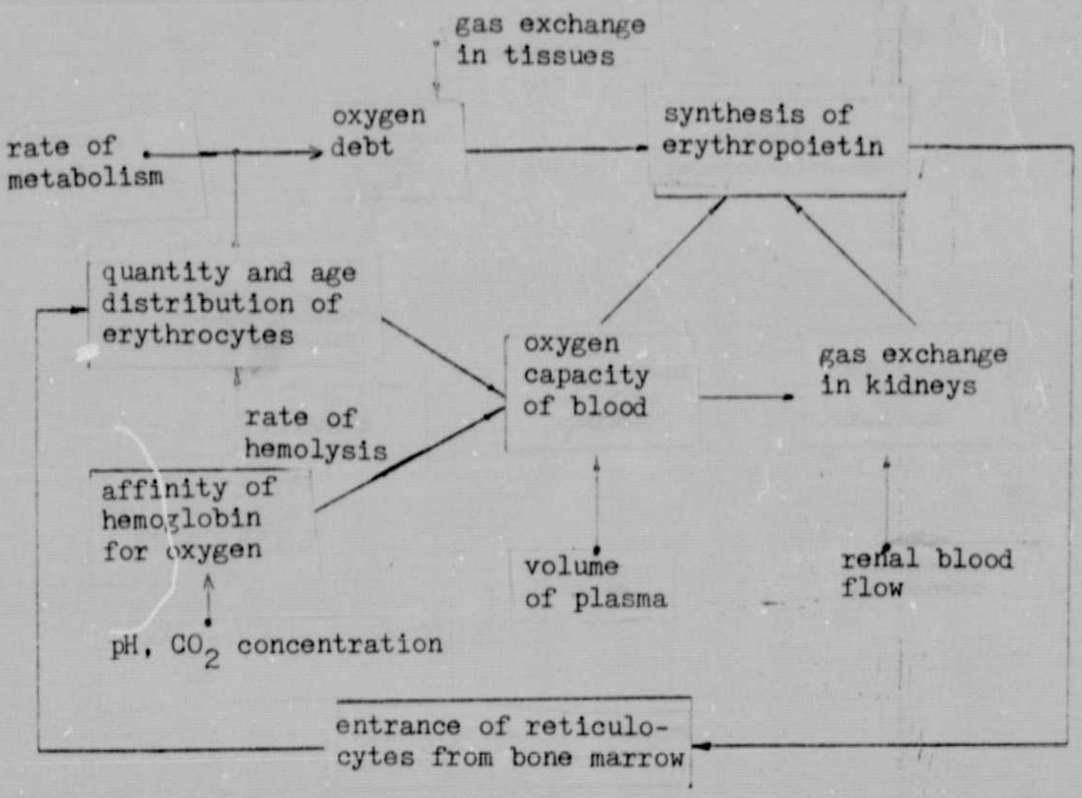

Figure 7. Block Diagram of Erythropoiesis Model

processes of gas exchange of fluid redistribution in the human organism, for example, in weightlessness. In order to obtain such an evaluation the model took into consideration the action of hydrostatic pressure on the system of pulmonary circulation, on the processes of transmembranous transport of fluids in the lungs and on the mechanics of respiration. /22

At present in science there is no single viewpoint on the mechanism for the formation of rhythmic respiration, however, the majority of the existing hypotheses and experimental data on this complex process make it possible to come to two main functional schemes of the respiratory center which are given in fig. 11 and 12. The main difference between them consists of the fact that in one case a break in inhalation and, consequently, the development of rhythmic respiration occurs due to pulsing from the receptors of lung stretching which enters the respiratory center by the vagus nerve. According to the other hypothesis

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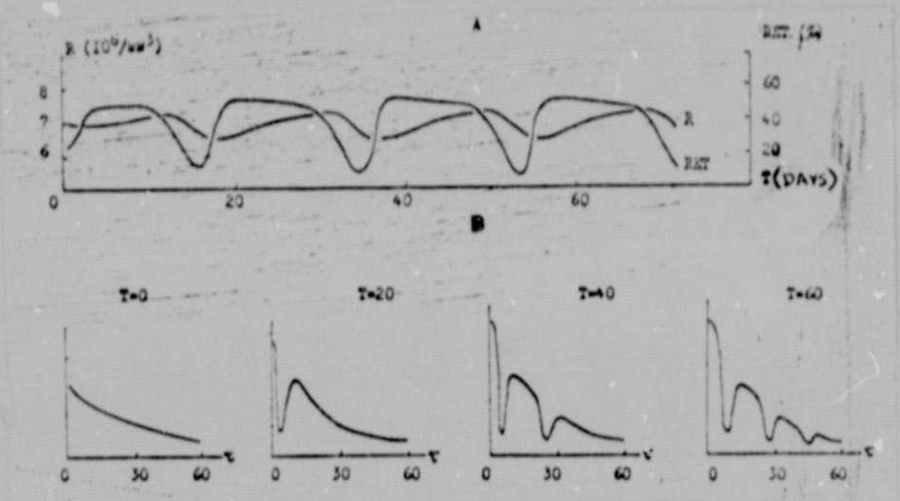

Figure 8

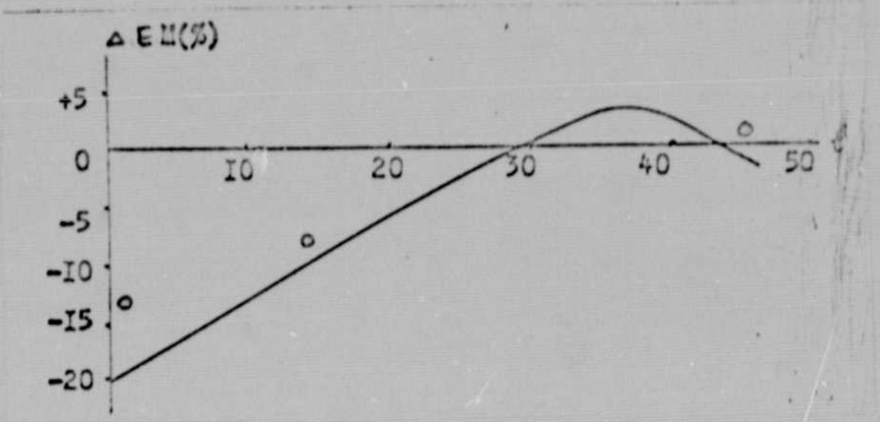

Figure 9

(fig. 12), the break in inhalation occurs without the participation of afferent pulsing, only due to the interaction of external neuron structures.

Study of the models constructed on the basis of each of the hypotheses showed that in relation to man these schemes supplement each other rather than compete. Thus, in the second case the respiration rate does not depend on the depth of inhalation, which is also observed in man with shallow breathing. According to the model based on the scheme in fig. 11, between the depth and

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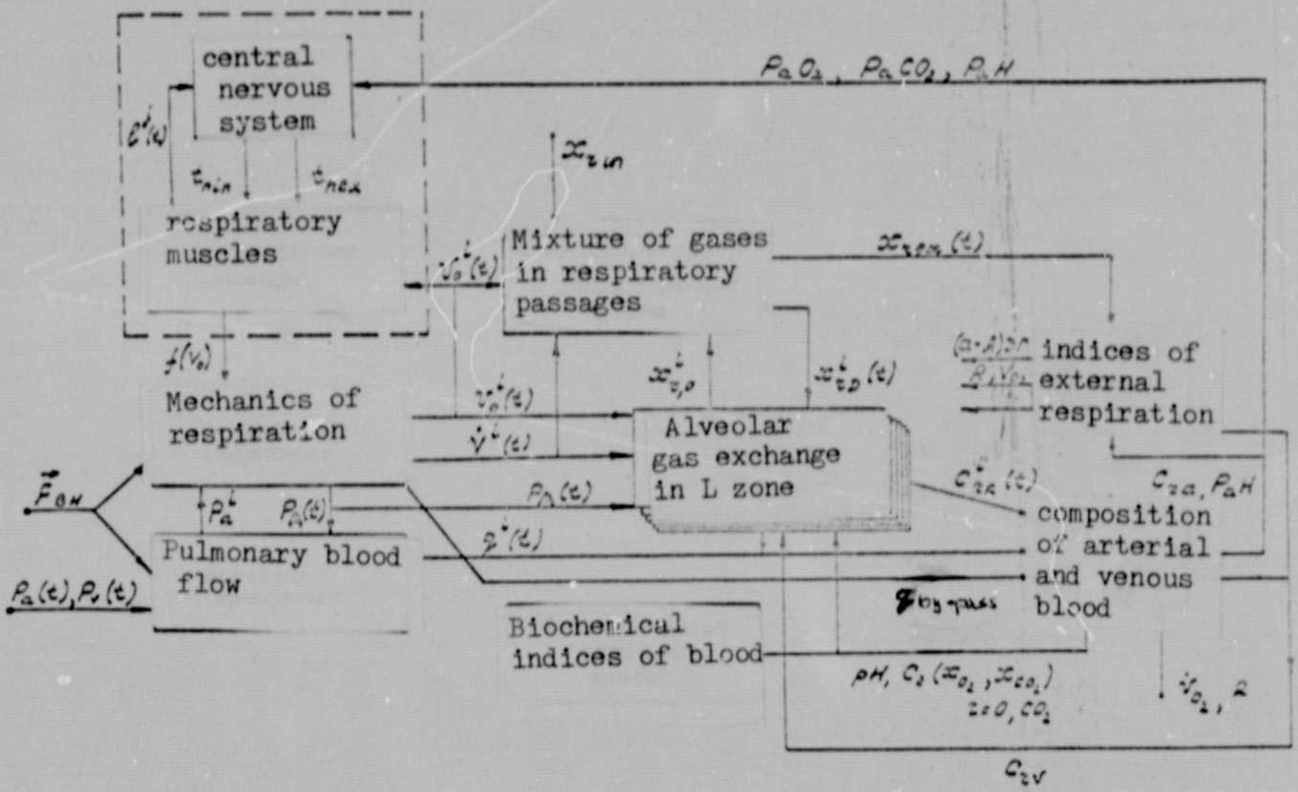

Figure 10. Block Diagram of Model for External Respiration

duration of inhalation a characteristic hyperbolic relationship is observed which it is customary to call the "curve of volume thresholds for the Hering-Breuer reflex." Comparison of the curve models with experimental data revealed their close coincidence.

On the basis of these studies we accepted the model of the respiratory center which had a variable structure: at prethreshold volumes of inhalation the respiratory center has a structure corresponding to fig. 12 and at above threshold volumes of respiration--fig. 11. The threshold was roughly 1 liter. This essentially indicates in man the existance of two mechanisms for the /26 discontinuity of inhalation: the first, inherited from animals and based on pulsing entering on the vagus nerve from receptors of pulmonary stretch, and the second, a higher nervous mechanism developed during evolution which ensures cessation of inhalation with small respiratory volumes at an earlier time than

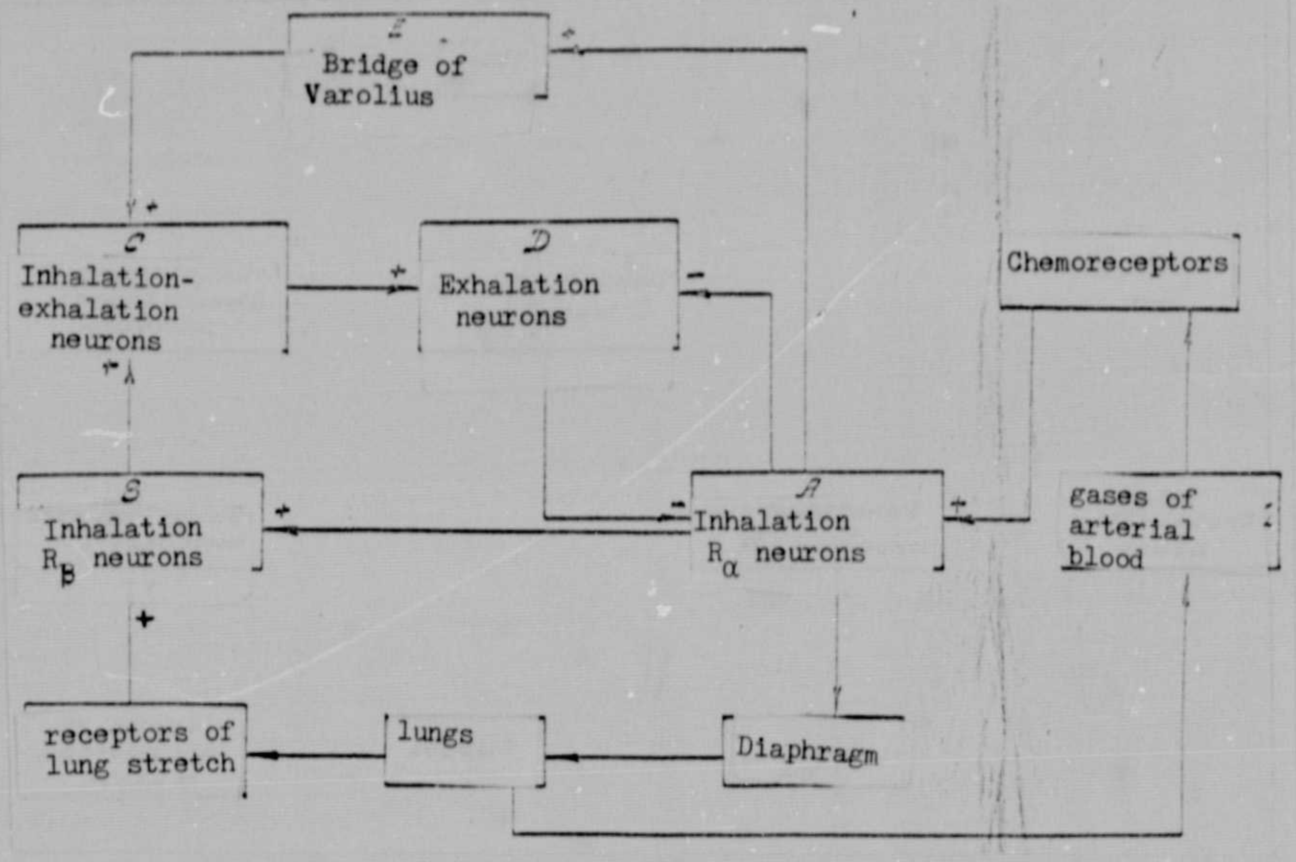

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Figure 11. Functional Scheme for Human Respiratory Center with Deep Breathing

that resulting from afferent pulsing from the lungs.

The obtained model satisfactorily describes the dynamics of activity in the main groups of respiratory neurons during the respiratory cycle and the changes in this activity during alterations of the chemical stimulus of respiration.

In the construction of the model for the controlled link the lungs are viewed as a homogenous viscoelastic system, that is, possessing elastic and inelastic pull, successively connected with the viscoelastic system of the abdominal organs and stretchable by the diaphragm muscles and the weight of the internal organs. In the description of the pulmonary gas exchange the lungs are viewed in the form of six parallel ventilated and parallel perfused gas exchange

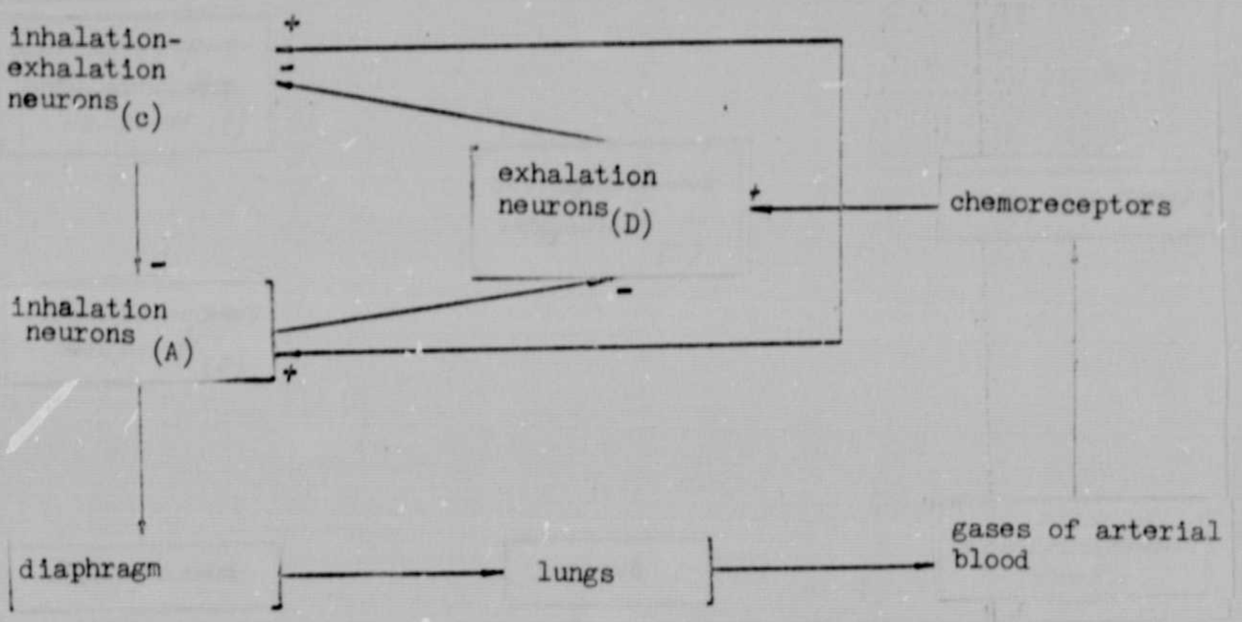

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Figure 12. Functional Scheme of Human Respiratory Center with Calm Breathing

units which differ in the amount of ventilation and the nature of the blood flow, and which are synchronously filled with air during inhalation and evacuated during exhalation. Parallel to the gas exchange units are "connected" an alveolar dead space corresponding to the unperfused upper zone of the lungs (third zone of West) and an alveolar by-pass corresponding to the unventilated lower layers of the lungs into which the respiratory passages are pinched by high intrapleural pressure.

Together with the indicated concept a variant was constructed for a model for lungs which represented a collection of a large number of parallel functioning uniform units. For each of these versions there exists its own class of tasks for which its use is most expedient.

The model of nonuniform lungs permits evaluation of the effects related to redistribution of blood and air in the lungs under the influence of external factors, as well as evaluation of the efficacy of the functioning of the external respiratory system under certain conditions. /27

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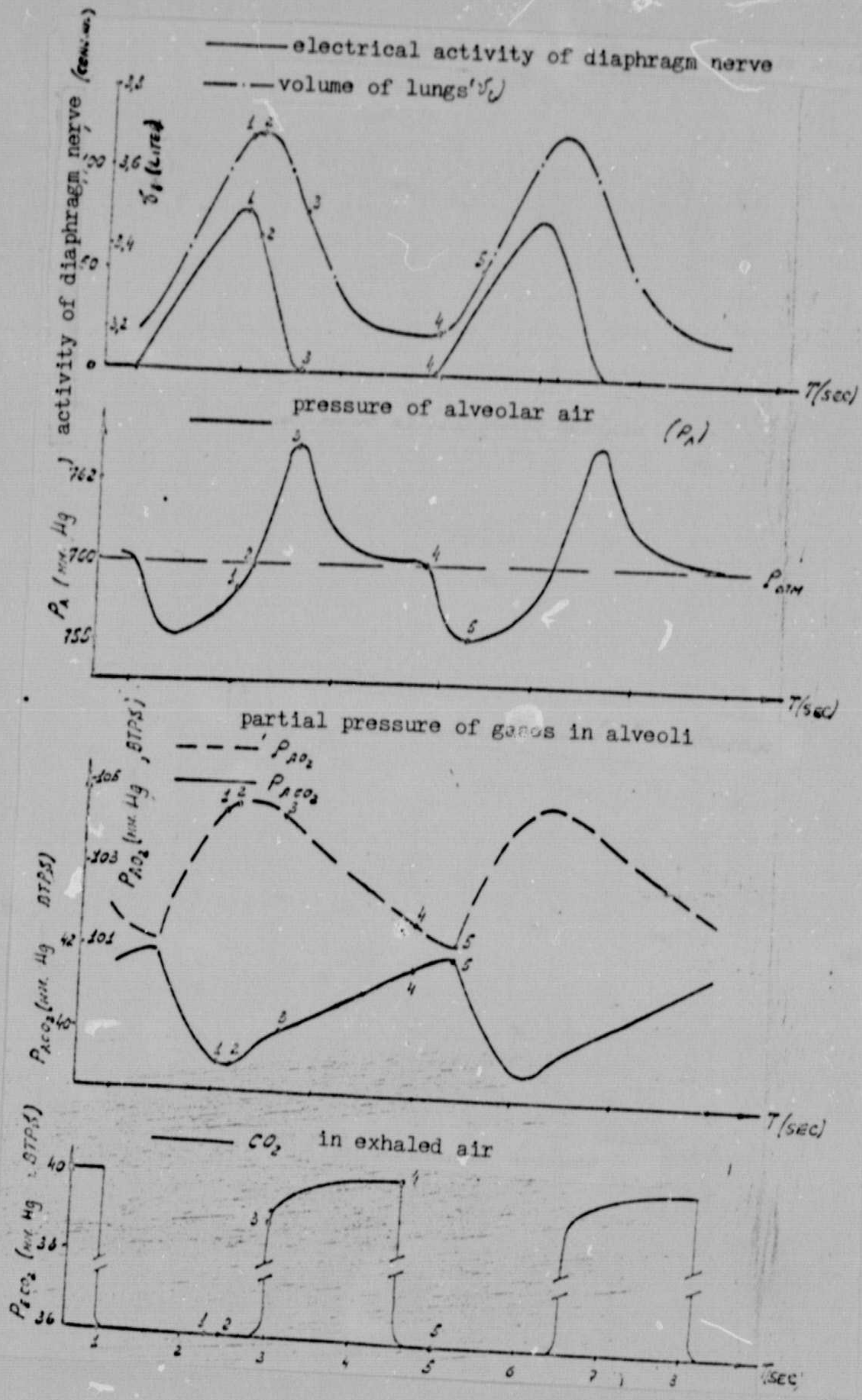
At the same time the model of homogeneous lungs permits calculation of the changes in the respiration rhythm, the rates of gas exchange and the composition of arterial blood with changes in the composition of the inhaled mixture. It is expedient to use this model to identify the immeasurable parameters of the external respiratory system. One of these tasks is the determination of characteristics of the respiratory center which are inaccessible for direct measurements; they are found by experimental curves for the change in volume of lungs, rate and composition of exhaled air, which can provide important information for prompt evaluation of the state of the higher nervous system in man under experimental conditions.

Figure 13 presents the results of calculation with a model of homogeneous lungs of the dynamics for the volume of lungs, composition and pressure of alveolar air. Sources [26-30] were mainly used in work on the model of the respiratory system.

The model for thermoregulation was developed with the help of the principles which to a great extent coincide with the conclusions of work [31]. The model we obtained is employed for computations of the biomechanical systems. An example of the computation of the organism's reaction to an increase in temperature from 25° to 48°C is shown in fig. 14. The figure depicts a change in temperature of the center of the torso T_R, temperature of the leg muscle T_M, mean temperature of the skin T_S and heat losses due to respiration E_V.

The state of the development and use of simulation models of physiological systems at the present time is characterized by the efforts of researchers to establish a harmonic correlation between the complexity of the models and the volume of that physiological knowledge which is available for their construction. The model is called upon to give either qualitative but not trivial results, or exact quantitative in simpler situations. However, in both of these cases it /29
is required to be reliable. Therefore at the current stage the models are used only for solving local tasks. The experience thus accumulated will be employed for their further refinement and integration.



(see next page)

Figure 13. Rhythm of Main Indices of External Respiratory System Computed by Model of Homogeneous Lungs. Designations: 1--moment of maximum strain of inhalation muscles; 2--end of inhalation; 3--moment of maximum pressure of alveolar air; 4--end of exhalation; 5--beginning of outer air entering alveoli during inhalation.

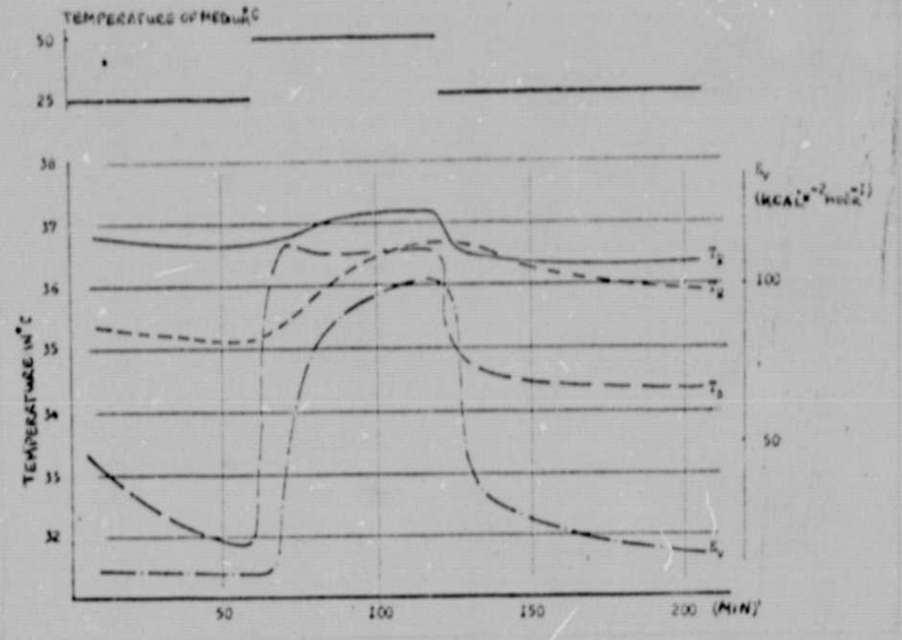


Figure 14. Example of Operation of Model for Thermoregulation

III. Problems and Perspectives /30

In conclusion we will briefly state our ideas on the future development of research in the area of predicting the state of human health during space flight.

1. One of the most important basic tasks of predicting we consider to be the development of methods of prediction in relation to the specific individual. The diversity in types and pronounced nature of reactions to the same conditions even among a comparatively uniform contingent is very great. It should be assumed that with an increase in the number of crews of space stations and a certain inevitable reduction in the selection requirements this diversity will increase even more. It is nearly evident that active control over the condition of different cosmonauts will vary. But individual assignments must not be made on the basis of mean statistical prediction.

2. The development of extrapolation methods of prediction requires a justified isolation of the more informative physiological indices and their combinations for this purpose. Further, it is expedient to use algorithms of this type directly on board the space craft.

3. Ground prediction will, apparently, develop along the path of harmonic combination of heuristic and formal procedures. Simulation modeling which occupies a seemingly intermediate position between these classes of methods, has, in our opinion, good perspectives. It is possible to use it, on the one hand, to "play back" diverse situations, taking into consideration the variety of probable influences, and to evaluate according to the data of observations the values of parameters which are difficult to measure, and on the other hand, to give useful support to medical experts who secure space flights.

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