Cybernetic Revolution and Forthcoming Technological Transformations (The Development of the Leading Technologies in the Light of the Theory of Production Revolutions)

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Cybernetic Revolution and Forthcoming Technological Transformations (The Development of the Leading Technologies in the Light of the Theory of Production Revolutions)*

Anton L. Grinin and Leonid E. Grinin

Abstract

The article analyzes the technological shifts which took place in the second half of the 20th and early 21st centuries and forecasts the main shifts in the next half a century. On the basis of the analysis of the latest achievements in innovative technological directions and also on the basis of the opportunities provided by the theory of production revolutions the authors present a detailed analysis of the latest production revolution which is denoted as 'Cybernetic'. The authors give some forecasts about its development in the nearest five decades and up to the end of the 21st century. It is shown that the development of various self-regulating systems will be the main trend of this revolution. The authors argue that at first the transition to the beginning of the final phase of the Cybernetic Revolution will start in the field of medicine (in its some innovative directions). In future we will deal with the start of convergence of innovative technologies which will form the system of MBNRIC-technologies (i.e. the technological paradigm based on medicine, bio- and nanotechnologies, robotics, IT and cognitive technologies). The article gives a detailed analysis of the future breakthroughs in medicine, bio- and nanotechnologies as well as some other technologies in terms of the development of self-regulating systems with their growing ability to select optimum modes of functioning as well as of other characteristics of the Cybernetic Revolution (resources and energy saving, miniaturization, individualization, etc.).

Keywords: *production revolutions, Neolithic revolution, Agrarian Revolution, Industrial Revolution, cybernetics, Cybernetic Revolution, science-informational epoch, medicine, biotechnology, nanotechnology, robotics, cog-*

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nitive technologies, self-regulating systems, epoch of self-regulating systems, miniaturization, individualization, information, control.

Introduction

Our article presents the analysis of contemporary technological shifts and forecasts the future technological transformations on the basis of the *theory of production principles and production revolution* which was introduced elsewhere (*e.g.*, Grinin 2006a, 2006b, 2007b, 2012b; Grinin L. E. and Grinin A. L. 2013; Grinin A. L. and Grinin L. E 2015; the history of the main technological changes is presented in these works). These new explanatory concepts are relevant for the analysis of causes and trends of major technological breakthroughs in the historical process and for the forecasting of new technological shifts. The article presents a general outline of this theory and analyzes its predictive capacities. The main part of the article is devoted to the analysis of the last production revolution – the Cybernetic Revolution – and the changes which took place in its course starting from the 1950s. The focus is on the changes which will most probably occur due to the Cybernetic Revolution in the next 30–60 years; for some aspects we have made forecasts up to the end of the 21st century.

Section 1. THE CYBERNETIC REVOLUTION: THE MAIN CHARACTERISTICS, JUSTIFICATION, AND THE METHODOLOGY OF FORECASTING

1. The Main Ideas and Implications of the Theory of Production Revolutions

According to the theory we have developed (Grinin 2006a, 2006b, 2007a, 2007b, 2012a; Grinin L. E. and Grinin A. L 2013; Grinin A. L and Grinin L. E 2015*), the most fundamental causes of transition from one stage of historical development to a subsequent one are global technological transformations which create an essentially new level of productivity and initiate a new technological epoch. We propose that these basic technological levels and epochs can be defined in terms of* production principles.

We single out four **production principles**:

1. Hunter-Gatherer.

2. Craft-Agrarian.

3. Trade-Industrial.

4. Scientific-Cybernetic.

Among large technological breakthroughs in history the most important are the three production revolutions: 1) the Agrarian or Neolithic Revolution; 2) the Industrial Revolution and; 3) the newest Cybernetic one.

Each production revolution launches a new production principle; so the three production revolutions represent the borders between four production principles (see Fig. 1).

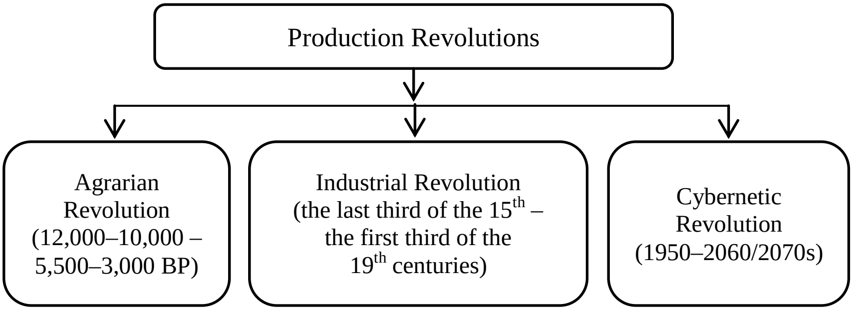

Fig. 1. Production revolutions in history

Each production revolution has its own cycle consisting of three phases: two innovative phases and between them – a modernization phase (see Fig. 2).

At *the initial innovative phase* a new revolutionizing productive sector emerges. The primary system for a new production principle emerges and for a long time it co-exists alongside old technologies. *The modernization phase* is a long period of distribution and development of innovations. It is a period of progressive innovations when the conditions gradually emerge for the final innovative breakthrough. At *the final innovative phase* a new wave of innovations dramatically expands and improves opportunities for the new production principle, which, at this time, attain full strength. As the final phase of the production revolution unfolds, the 'essence' of the production principle, its opportunities and limitations are revealed, as well as the geographical borders of its expansion in respect different climates, soils, diets, *etc*.

The production revolutions also bring about:

1. The development of fundamentally new resources.
2. A vigorous growth of production output and population.
3. Substantial complications to society.

(For more details see Grinin 2006b, 2007b, 2012b; Grinin L. E. and Grinin A. L. 2013; about Industrial Revolution see Grinin and Korotayev 2015a).

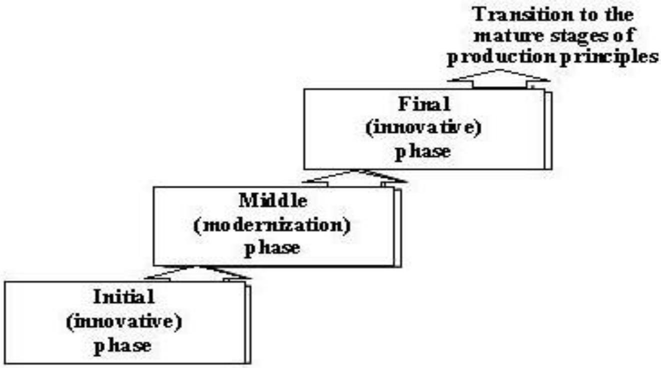

Fig. 2. The structure of production revolutions (phases and their types)

The Agrarian Revolution was a great breakthrough from hunter-gatherer production principle to farming. Its **initial innovative phase** was a transition from hunting and gathering to primitive hoe agriculture and animal husbandry (that took place around 12,000–9,000 BP).[1] The **final phase** was a transition to intensive agriculture (with large-scale irrigation and plowing) which started around 5,500 years ago. These changes are also presented in Table 1.

Table 1. The phases of the Agrarian Revolution

Phases	Type	Name	Dates	Changes
Initial	Innovative	Manual agriculture	12,000–9,000 BP	Transition to primitive manual (hoe) agriculture and cattle-breeding
Middle	Modernization	No designation*	9,000–5,500 BP	Emergence of new domesticated plants and animals, development of complex agriculture, emergence of a complete set of agricultural instruments
Final	Innovative	Irrigated and plow agriculture	5,500–3,500 BP	Transition to irrigative or plow agriculture without irrigation

Note: * In this and Table 2 below the titles are given only to the innovation phases; the modernization phases do not need special designation.

[1] Following Gordon Childe (1950), the Agrarian Revolution is often called the Neolithic one. However, this notion is not quite satisfactory. First, it actually started during the Mesolithic era; second, it completed already in the Iron Age. One should not confuse the Agrarian Revolution as a global phenomenon with the British Agrarian Revolution of the 17th – 18th centuries (on the latter see, *e.g.*, Overton 1996; see also Grinin and Korotayev 2015a).

The Industrial Revolution was a great breakthrough from craft-agrarian production principle to machine industry, marked by intentional search for and use of scientific and technological innovations in the production process.

Its **initial phase** started in the 15th and 16th centuries with the development of shipping, technology and mechanization based on the watermill as well as with a 'more organic' (Durkheim 1997 [1893]) division of labor. The **final phase** was the well-known breakthrough of the 18th and 19th centuries with the introduction of various machines and steam energy (for more details about Industrial Revolution see Grinin 2007b; Grinin and Korotayev 2015a). These changes are presented in Table 2.

Table 2. The phases of the Industrial Revolution

Phases	Type	Name of the phase	Dates	Changes
Initial	Innovative	Manufacturing	15th – 16th centuries	Development of shipping, technology and mechanization on the basis of water engine, development of manufacture based on the division of labor and mechanization
Middle	Modernization	No designation	17th – early 18th centuries	Formation of complex industrial sector and capitalist economy, increase in mechanization and division of labor
Final	Innovative	Machinery	1730–1830s	Formation of sectors with the machine cycle of production using steam energy

The Cybernetic Revolution is a great breakthrough from industrial production to the production and services based on the operation of self-regulating systems.

Its **initial** phase dates back to the 1950–1990s. The breakthroughs occurred in the spheres of automation, energy production, synthetic materials production, space technologies, exploration of space and sea, agriculture, and especially in the development of electronic control facilities, communication and information. We assume that the **final** phase will begin in the nearest decades, that is in the 2030-s or a bit later, and will last until the 2070s.

We denote the initial phase of the Cybernetic Revolution as **a scientific-information** one, and the final – as **a phase of self-regulating systems**. So now we are in its modernization phase which will probably last until the 2030s. This intermediate phase is a period of rapid distribution and improvement of the innovations made at the previous phase (*e.g.*, computers, internet, cell phone, *etc.*). The technological and social conditions are also prepared for the future breakthrough. *We suppose that the final phase of the Cybernetic Revolution will lead to the emergence of many various self-regulating systems*.

The scheme of the Cybernetic Revolution is presented in Fig. 3.

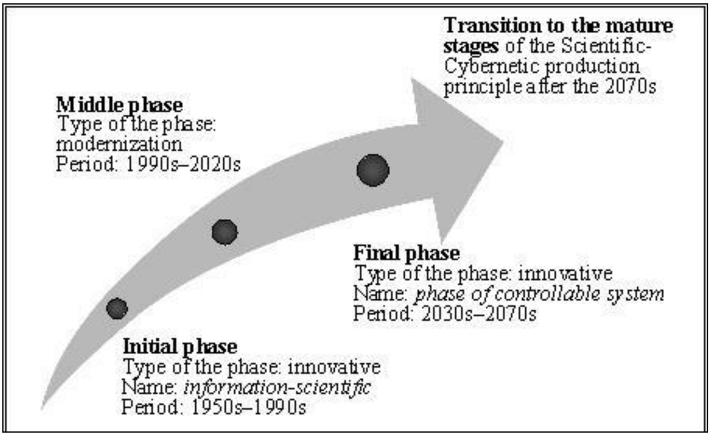

Fig. 3. The phases of the Cybernetic Revolution

2. Characteristics of the Cybernetic Revolution

2.1. The main characteristics of the Cybernetic Revolution

Below we enumerate the most important characteristics and trends of the Cybernetic Revolution and its technologies. One can observe them today, but they will be realized in mature and mass forms only in the future. These features are closely interconnected and corroborate each other.

The most important characteristics and trends of the Cybernetic Revolution:

1. The increasing amounts of information and complication of the systems of its analysis (including the ability of the systems for independent communication and interaction);

2. Sustainable development of the system of regulation and self-regulation;

3. Mass use of artificial materials with previously lacking properties;

4. Qualitatively growing controllability a) of systems and processes of various nature (including living material); and b) of new levels of organization of matter (up to sub-atomic and using tiny particles as building blocks);

5. Miniaturization and microtization[2] as a trend of the constantly decreasing size of particles, mechanisms, electronic devices, implants, *etc.*;

6. Resource and energy saving in every sphere;

[2] See: http://www.igi-global.com/dictionary/microtization/18587.

7. Individualization as one of the most important technological trends.

8. Implementation of smart technologies and a trend towards humanization of their functions (use of the common language, voice, *etc.*);

9. Control over human behaviour and activity to eliminate the negative influence of the so-called human factor.[3]

The characteristics of the technologies of the Cybernetic Revolution:

1. The transformation and analysis of information as an essential part of technologies;

2. The increasing connection between the technological systems and environment;

3. A trend towards autonomation and automation of control is observed together with the increasing level of controllability and self-regulation of systems;

4. The capabilities of materials and technologies to adjust to different objectives and tasks (smart materials and technologies) as well as capabilities for *choosing optimal regimes in the context of certain goals and tasks*;

5. A large-scale synthesis of the materials and characteristics of the systems of different nature (*e.g.*, of animate and inanimate nature).

6. The integration of machinery, equipment and hardware with technology (know-how and knowledge of the process) into a unified technical and technological system;[4]

7. The self-regulating systems (see below) will become the major part of technological process. That is the reason why the final (forthcoming) phase of the Cybernetic Revolution can be called **the epoch of self-regulating systems** (see below).

Various directions of development should generate a system cluster of innovations.[5]

2.2. Why is the latest production revolution denoted as 'Cybernetic'?

The theory of production revolutions proceeds from the assumption that the essence of these revolutions can be most clearly observed only during the fi-

[3] For example, the control of human insufficient attention in order to prevent dangerous situations (*e.g.*, in transport) as well as to prevent human beings from using means of high-risk in unlawful or disease state (*e.g*., not allow driving a motor vehicle while under the influence of alcohol or drugs).

[4] During the Industiral Epoch these elements existed separately: technologies were preserved on paper or in engineers' minds. At present, thanks to informational and other technologies the technological constituent fulfils the managing function. And this facilitates the path to the epoch of self-regulating systems.

[5] Thus, for example, the resource and energy saving can be carried out via choosing optimal modes by the autonomous systems that fulfil specific goals and tasks and *vice versa*, the choice of an optimum mode will depend on the level of energy and materials consumption, and a consumer's budget. Or, the opportunities of self-regulation will allow choosing a particular decision for the variety of individual tasks, orders and requests (*e.g.*, with 3D printers and choosing of an individual program as the optimal one).

nal phase. One can retrospectively outline the future features in initial and middle phases, but they do not form a clear system yet. Thus, the designation given to the third production revolution is based on our forecasts concerning its final phase. We suppose that *the most important thing about this phase will be a wide use of* ***the principle of self-regulation and self-controlling in different technological systems*** *which as a result will transform into self-regulating systems. At the same time in the systems of new type, the characteristics of living matter will combine with technological principles.* We denote this revolution as 'Cybernetic' as it will lead to the transition to a wide spread of self-regulating systems. The analysis of such systems can be based on the ideas of cybernetics which is a study in controlling different complex regulated systems via the processes of receiving, transformation and transfer of information (see, *e.g.*, Wiener 1948; Ashby 1956; Beer 1959; Foerster and Zopf 1962; Umpleby 1999; Tesler 2004).

Cybernetics can also be defined as a study of general laws of receiving, storage, and transfer of information in complex controllable systems. In any case the notions of regulation and information are considered as the most important ones for cybernetics, as it is impossible to control anything without transforming information. Within the Cybernetic Revolution, the technologies connected with information processing and more complex systems of control become of utmost importance. That is the reason why it makes sense to consider the changes in information technologies as the initial phase of the Cybernetic Revolution since information technologies are the basis of a transition to regulating technologies. Regulation and self-regulation (as the highest form of regulation) in systems are also the most important categories in cybernetics.

2.3. What are self-regulating systems?

Thus, *the main characteristic of the Cybernetic Revolution is a transition to creation and wide distribution of the special kind of systems: controllable systems (in some respect they can be denoted as standalone systems, i.e. systems which are able to operate independently), and the systems of higher level – self-regulating ones*.

Let us explain. *Controllable (standalone) systems are based on* ***the principle of controllability****, this means a higher level of control which is not a direct human control but a control via some inanimate system or subsystem of control (technical or of some other kind). In fact such kind of regulated systems should have a greater autonomy.* Just as even a primitive machine differs from a mechanical appliance, so the control by the autonomous systems differs from human control or control by means of primitive appliances. The highest level of controllability will be denoted as ***self-regulation.***

Self-regulation and self-regulating systems. Self-regulating systems are systems that due to the embedded programs and intellectual (and other) components can regulate themselves, responding in a pre-programmed and intelligent way to the feedback from the environment[6] as well as independently operate (or suggest alternatives) in a wide range of variations, having opportunities for *choosing optimum regimes in the context of certain goals and tasks*. They are the systems that operate with minimal to zero human intervention.

On the whole, this refers to the type of regulation via the technologies which allow the systems: a) to work most of the time without human interference as a part of control; b) to have more opportunities to independently respond to changes and to make operative decisions (and in future responsible decisions as well); c) to self-regulate and to self-adapt. In other words, due to special technologies one can allow the required processes to proceed autonomously, intervening only in the case of unexpected deviations from the predetermined parameters or in the case of some important reset of the parameters (of course, it is necessary to provide the signal about changes in parameters and a message inquiring the permission for some changes, or a number of possible options will be provided). Let us emphasize that this refers not only to technical but also to biological, compound or some other kind of systems.

Today there are many self-regulating systems around us, for example, the artificial Earth satellites, pilotless planes, navigators laying the route for a driver. Another good example is life-supporting systems (such as medical ventilation apparatus or artificial heart). They can regulate a number of parameters, choose the most suitable mode and detect critical situations. There are also special programs that determine the value of stocks and other securities, react to the change of their prices, buy and sell them, carry out thousands of operations in a day and fix a profit. A great number of self-regulating systems have been created. But they are mostly technical and informational systems (as robots or computer programs). During the final phase of the Cybernetic Revolution there will emerge a lot of self-regulating systems connected with biology and bionics, physiology and medicine, agriculture and environment. The number of such systems as well as their complexity and autonomous character will dramatically increase. Besides, they will essentially reduce energy and consumption of resources. Human life will become organized to a greater extent by such self-regulating systems (e.g., by monitoring of health, regulation of or recommendations concerning physical exertion, diet, and other controls over the patients' condition and behaviors; prevention of illegal actions, etc.). As a result, the opportunity to control various natural, social and industrial production processes without direct human intervention (which is impossible or extremely limited at present) will increase.

[6] The connection with the environment and the 'selection' of this or that 'decision' by the system on the basis of environment changes are also the most important ideas in cybernetics.

Nowadays, there are a number of so-called 'smart' technologies and things which in a proper and rather flexible way respond to external impacts. The simple but very illustrative example here can be mattress or pillows which take (or remember) the form of body (head) of a user; another example is chameleon sunglasses which change the intensity of sun protection depending on the brightness of the sunlight. However, in such technologies as well as in some automatic systems like auto-open doors, auto-switch light, *etc.* only some elements of self-regulation are applied. Within self-regulating systems, the processes of identification, memorizing and selection of regime should proceed on a much larger scale; it will often be the choice within the framework of uncertain opportunities. One can say that 'smart' technologies with the elements of self-regulation have the reaction amplitude within the predetermined spectrum. In such device like temperature regulator (connected through WiFi to Internet) which memorizes the climatic habits of an individual in a given period of time, the amplitude of preferences is rather small. Whereas for self-regulating systems, the amount of variations is largely unlimited, such a system is capable of choosing a proper action model in any combination within the framework of its opportunities. Let us consider the navigator. There are usually several routes to reach the destination, but since navigators can get direction from every point the number of routes is practically not limited. That is why navigator is supposed to lead the driver to the destination from any place. This is an example of self-regulation system of rather high level, though the device itself is not too complicated. The number of routes to reach the destination is not limited (as even when there are several possible routes the amount of variations becomes large). However, in any situation the navigator should bring the driver to the point of destination from any place. Here the degree of self-regulation can be considered as a higher one, though the device itself is not too complicated.

2.4. The main directions of the Cybernetic Revolution

We suppose that during the final phase of the Cybernetic Revolution different *developmental trends should produce the effect of a system cluster of innovations as is often the case with the innovative phases of production revolutions*. Thus, if we consider the forecasts for the final phase of the Cybernetic Revolution in our opinion *the general drivers of the final phase of the Cybernetic Revolution will be medicine, bio- and nano- technologies, robotics, IT, cognitive sciences, which will together form a sophisticated system of self-regulating production.* We can denote this complex as **MBNRIC-technologies.**[7]

Another question is in what sphere will the final phase of the Cybernetic Revolution start? Which one will be the first? First of all, one should remember

[7] As is known, there is a widely used abbreviation of NBIC-technology (or convergence), that is nano-bio-information and cognitive (see, *e.g.*, Lynch 2004; Dator 2006; Akayev 2012). However, we believe that this complex should be expanded.

that the 'breakthrough' sphere will be narrow as it happened during the Industrial Revolution (when the breakthrough occurred in a narrow field – cotton industry). In a similar way, we assume that the Cybernetic Revolution will start first in a certain area. Given the general vector of scientific achievements and technological development and taking into account that a future breakthrough area should be highly commercially attractive and have a wide market, we predict that the final phase (the one of self-regulating systems) of this revolution will begin in one of the new branches of medicine. Perhaps, it has already formed (as biomedicine or nanomedicine) or it can form as a result of involving other innovative technologies into medicine. However, the development will follow the path of spreading the self-regulating systems into different new fields, their integration and development of the complex of MBNRIC-technologies.

Our assumption that the first field will be a new branch in medicine is based: a) on the analysis of the latest achievements in technologies; b) on a number of demographic and economic trends (see below); c) on the regularities obtained from the theory of production revolutions which we analyze in the following section. This section will define these regularities and the way they can be used in forecasting.

3. The Logic of the Production Revolution: The Analysis of Utility and Correlations between the Phases

Let us remind that the fundamental idea of the proposed conception of production revolutions is that *for every production revolution each of its three phases plays functionally the same role and the ratio between the duration of phases within the framework of each cycle remains approximately the same*. Thus, on the basis of the regularities identified within the Agrarian and Industrial Revolutions, one can make assumptions about the following factors:

first, about the duration of the middle (modernization) phase of the Cybernetic Revolution;

second, about the beginning and approximate duration of the final phase of the revolution;

third, about the sectors and directions that will be affected by the new technological breakthrough.

Therefore, the theory of production revolutions provides with methodological approach to ground our forecasts about the future technological shifts within the Cybernetic Revolution. Let us remind the reader that the initial phase of the Cybernetic Revolution has already been completed (lasting from 1950 to the early 1990s) and the modernization one is approximately half way through its development (it started in the 1990s and presumably will last till the end of the 2020–2030s). So we can compare the forecasts of the theory concerning each phase of the production revolution with present-day reality, and we can also infer the role that technologies will play in the final phase of the Cybernetic Revolution.

To give a better explanation to such a methodology, we formulate a number of functional and processual relations between the initial and final phases of the production revolution, between the initial and middle phases, and between the middle and final phases of the production revolutions. Knowing the algorithm of how processes manifested in the initial phase of the production revolution can be transformed in the middle and final phases, we provide forecasts of the Cybernetic Revolution development for the upcoming decades proceeding from the study of its initial and uncompleted middle phase.

3.1. The peculiarities of the initial phase: Amalgamation of non-system tendencies into a system and the development of new ones

The initial phase of the production revolution is marked by the following peculiarities:

1. *A number of tendencies and innovations that used to be non-systemic within the previous production principle get a systemic character*. The non-systemic character means that within the previous production principle these phenomena did not play a crucial role and did not result from its main characteristics, whereas within a new production principle the role of these characteristics significantly increases. This can be shown by the example of automatization which to a certain extent was developed within industrial production long before the Cybernetic Revolution. One of the main characteristics of the industrial production principle is that the production process is carried out by means of machines which are operated by humans using their sense organs, power and qualification. At the same time, some operations were performed without human involvement, in other words automatically. But the automatization of processes was not essential, in other words it was not a necessary characteristic of the industrial production principle but an extra bonus. In the early 20th century, automatization started to develop vigorously (*e.g.*, in electrical engineering for the prevention of accidents, in engines for convenient control, *etc.*). But still it had no decisive importance as it was not generally used for the automatization of technological processes.

Therefore, in that period automatization can be regarded as a hyper-development of such essential characteristic as mechanization. Besides, in the first half of the 20th century, automatization was not the leading direction of the industrial production principle. On the contrary, the leading position was taken by the processes of the latest division of labor including the wide distribution of assembly-flow production (a constant intensifying division of labor is an essential and transparent characteristic of the industrial production principle, strikingly manifested already in manufactures). The development of automatization in the second half of the 20th century is quite a different matter. It has become the most important characteristic of the scientific-cybernetic production principle (in its initial stages), finding new forms of application and expression in releasing human costs in process control (especially in Information and Communications Technology [ICT]).

Thus, *the initial phase of the production revolution develops the non-system elements of the previous period to the highest degree.* In this regard, automatization was the continuation of mechanization (see *e.g.*, Lilley 1966; Philipson 1962; Bernal 1965); as the chemistry of synthetic materials was the continuation of organic chemistry (Zvorykin *et al.* 1962); and as the Green Revolution in agriculture was the continuation of agronomy (Thirtle *et al.* 2003). The development of radio and television technologies was the continuation of the trend of new methods of information transfer which had emerged earlier. Such continuity can hide the intensity of the transition from one epoch to another. So it is not surprising that in the 1950–1970s the scientific and technological development was considered as the continuation of the Industrial Revolution, and at best it was defined as a new industrial revolution (scientific and technical revolution [Bernal 1965]). However, this super-development possessed some qualitative characteristics which will be described below.

2. *The former non-system characteristics together with newly emerging ones now merge into a unified system representing a new production principle.* Automatization, the chemical production of synthetic materials, the powerful development of non-computer electronics and means of communication, the emergence of various engines, the general transition to a new type of energy and fuel, the breakthrough in selection and plant protection, the discharge of a million workers previously employed in agriculture and industry and their transition to the service sector; together with a number of new directions in technology, informatics and science – all this creates a principally new situation in economy and also evidences the start of a new production revolution, namely, the Cybernetic one.

3. *An important factor with a powerful synergistic effect is the temporal density (the cluster pattern) of the formation and development of a number of directions which, to a greater or lesser extent, is typical of a new production principle.* Such directions in the 1950–1960s were the nuclear power industry, space exploration and usage of space frequencies for communication and other purposes, deep-sea exploration, information and computer technologies, multiplying equipment, laser technologies, and other areas (*e.g.*, in genetics, medicine and biotechnology).

4. *However, the future of these innovative spheres can be different*: some of them get particular and important development in the second half of the initial phase and in the middle phase; and other areas will not develop so intensively. Some can turn (at least, temporally) into dead-ends. Thus, at present the atomic energy industry faces severe constraints due to environmental problems,

the hopes to master thermonuclear energy fell short of expectations and deep-sea exploration (except for shelf sea) still remains exotic. At the same time, the development of ICT has become the leading trend.

5. *The change of the leading sector in the course of the production revolution.* The leading role of the peculiar characteristics and sectors of a new production principle becomes especially obvious by the end of its initial phase or during its modernization phase (as in the case with ICT). These sectors need some time to reach maturity and acquire a systemic character. *Thus, during these two first phases of the production revolution there is a constant alteration of the leading branches and sectors as well as the formation of new sectors.* One of the branches of a new production principle starts to dominate over the other branches for quite a long period of time (from the end of the initial phase until the middle phase). This branch becomes a key symbol of the production revolution and its driving force. *But later its role as a driving force decreases.* Thus, the wool industry (the most important branch of the initial phase of the Industrial Revolution) appeared to be unimportant in the final phase when it was replaced by the cotton industry.[8] So one can make an assumption that ICT will not remain the most important sphere of the final phase of the Cybernetic Revolution. Besides, advancements in this field will become only one constituent (albeit an important one) of the breakthrough which will be made in other fields.

Later, in the course of the final phase of the Cybernetic Revolution (approximately in the 2040–2050s) one can expect a new qualitative breakthrough in ICT. For example, one can assume that sooner or later serious changes will inevitably occur in programming itself. At present this process is labor-intensive and slow. It will most likely develop in the direction of simplification and robotization of some part of programming and especially in implementation of programs. In other words, machine programming will mainly substitute human programmers and 'the self-programming' trend will be developed.

6. *Already in the initial phase there emerges a prototype of the sectors which will become the leading ones in the final phase. But in the initial phase they do not play the leading role* (see below).

3.2. The characteristics of the middle (modernization) phase: accumulation of innovations and the search for a breakthrough point

1. *The large scale of already existing tendencies and the formation of new ones.* On the one hand, in this phase many processes develop (to a varying degree) that were formed in the initial phase of the production revolution. On the other hand, in the modernization phase we can trace the roots of those forms which

[8] Animal husbandry which developed in the modernization phase of the Agrarian Revolution did not become the leading direction of the final phase of this revolution.

will emerge as leaders in the final phase of production revolution. Therefore, it is important to distinguish between the tendencies which have already appeared to be mature and the tendencies which are only formed.

2. *The expanded development. Need for profound social and political changes.* The expansion of new technologies is especially noticeable in the first half of the modernization phase. In its second half this expansion faces certain saturation and slows down and this increases activity in the field of innovations. There appears an anticipation of something important. But the decisive component for the formation of a new system is still lacking. Besides, this gap can be manifested not only in the absence of basic technological innovations but also of the social conditions for its implementation. One of the most important characteristics of the modernization phase is that *during this period some profound changes or even breakthroughs in social and political relations should take place*. As regards the Industrial Revolution, the period between the seventeenth and eighteenth centuries is the time of social revolutions in England, the Netherlands, the USA, and France which changed the world. It was also the time of changes in the world policy: The Thirty Years' War (1618–1648) and the subsequent Piece of Westphalia laid the foundations of international relations for a long time. Globalization and the period which we denoted as the epoch of new coalitions (Grinin 2009, 2012c; Grinin and Korotayev 2010, 2015a) will also significantly change the world and this process is already underway.

3. *The idea of a decisive component*. During the modernization phase opportunities and improvements accumulate that will play a role in making the final phase of the revolution possible. All components should be ready before it starts. However, we emphasize that the innovations will form a new system only as soon as the key component emerges. At the same time the reconstruction of the relationships within the framework of a whole production system (fields, branches and innovations according to their value) will be considerable.

4. *The emergence of the decisive innovation in the new field.* Basing on our analysis of production revolutions one can conclude that the decisive innovation will appear not within the most important sector of the economy. Thus, irrigated agriculture failed to become the most important sector of agriculture in pre-state barbarian societies; while the cotton industry was not the most important industrial sector in the first half of the 18th century. Moreover, in this field there should appear certain conditions which should include high commercial profitability and attraction, thus producing a steady demand for a long period of time. Nevertheless, the emergence of the decisive innovation can remain underestimated for some time.

The decisive innovation for the final phase of the Cybernetic Revolution to begin can appear in different fields of bio- or nanomedicine (or some other new branch of medicine). There can be a series of innovations which will turn the growing number of innovations into a qualitatively new system. It is quite possible that such a breakthrough will be connected with the invention of successful methods to fight cancer as this disease differs significantly from other diseases and requires solutions at the genetic level as well as the application of fundamentally new technologies.

3.3. The peculiarities of the final phase

1. *The main characteristics of the production revolution come to maturity.* One can find all the basic characteristics of the final phase of the revolution already in its initial phase though in undifferentiated, incomplete or undeveloped state. These characteristics of the future system are revealed in the middle phase when the production principle takes a relatively complete although undeveloped form.

Thus, one may infer about the main characteristics of the Cybernetic Revolution on the basis of an analysis of the initial and middle phases, through a focus on their features and the dynamics of development. This analysis allows for a singling out of the most important characteristics of the Cybernetic Revolution including resource savings, miniaturization, individualization, wider use of artificial and smart materials, *etc.* These characteristics already show up in our epoch but they will absolutely dominate in the next epoch.

2. Given the *numerous directions that will appear during the initial phase, there will be some that will necessarily become leading directions in the final phase.* At the same time in the initial phase they play a less significant role. Thus, while in the final phase of the Industrial Revolution the main point is mechanisms, machines, replacement of manual labor by machinery, in its initial phase machinery was only a part of this new direction. In the beginning of the Industrial Revolution, the technical innovations (replacement of manual labor by machines) were not so important and the main point was the process that intensified the division of labor. If you consider the Agrarian Revolution, the leading direction of manual (hoe) agriculture was the use of fertile areas with the help of manual labor (*e.g.*, with the help of a sharp stick or stone hoe). The soil fertility was natural or was achieved by burning of plants. As to irrigation technologies, in the initial phase of the Agrarian Revolution they were not so widespread and were linked to the local environment. But in the final phase they became the leading factors and remained such during the whole period during which the craft-agrarian principle dominated production.

Therefore, the leading sector of the final phase of the Cybernetic Revolution has already formed, but it is one of those sectors which do not, as yet, play a decisive role in the economy. In our opinion, medicine (one of its new branches) will play the leading role in the unfolding final phase of the Cybernetic Revolution (see below).

3. *The mutual integration of innovative sectors starts after the formation of the decisive innovations or their group.* This process especially intensifies in

the final phase of the production revolution. Innovations are mutually integrated and form a fundamentally new system. That was the case with the invention of the power spinning loom in the 1760s (which was then constantly being improved). The important inventions and directions of industrial production such as primitive steam engines, steam energy, new types of machines, the principles of management at large enterprises, the current institution of inventions and different technical innovations which had already existed before, after the invention of the power spinning loom allowed during two decades to form the fundamentally new sector of cotton mills (as well as the great idea that all manual operations can be mechanized). This caused the cumulative effect of rapid invention of missing innovations in the field of cotton carding (*i.e.*, the separation of cotton fibers), painting, printing, *etc.*

Thus, the breakthroughs in medicine and allied technologies will cause the 'catching up' and an amalgamation of different innovations into a system which might bring about the completion of the Cybernetic Revolution (see below).

4. One should *distinguish between the field of breakthrough and the essence of a new system of production.* The field of breakthrough just initiates profound transformations. The production revolution will fully gain its logic and 'sense' or 'essence' only later when the transformations become profound and expanded. However, one can try to guess this 'meaning', 'sense' and 'essence' on the basis of the processes occurring during the initial and middle phases of the production revolution.

Thus, the general idea of the Cybernetic Revolution can be connected with a constant and comprehensive saving of energy, resources and materials which will start due to mass development of self-regulating systems at a fundamentally new level. In fact, without the breakthrough in saving there will be no growth of living standards of the world's population whose number will increase at least until the 2070s (according to most forecasts, see, *e.g.*, Population Division 2012).

3.4. The determination of the future sector of the breakthrough. Why medicine?

Thus, an assumption from the theory of production revolutions entails that one of the number of directions defined in the initial and middle phases of any production revolution becomes a breakthrough area by the beginning of its final phase. But this factor does not play a leading role in the economy until the beginning of the breakthrough.

The analysis of the actual development of production revolutions also suggests the following characteristics of the future sector:

- the commodity produced in this sector should be of prime necessity. Thus, cereal in the period of the Agrarian Revolution and cotton in the period of the Industrial Revolution were basic necessities;
- the direction of development of the sector should conform to the leading tendencies and problems in the society (irrigation agriculture could support and increase the sudden exponential population growth; the cotton industry met the needs of increasing urbanization and made use of the surplus labor force which had emerged in the agrarian sector);
- the sector can influence a significant number of spheres and integrate them (*e.g.*, in the period of the Agrarian Revolution the irrigation facilities required joint actions in society; and in the period of the Industrial Revolution the transition to machines and steam-engine in the cotton industry caused a rapid growth of economy, the reconstruction of transportation routes and trade);
- technological conservatism in this sector is relatively weak;
- the breakthrough sector should provide high profits and rely on steady demand, otherwise it will fail to attract major investments. Besides, borrowing from this sector new technologies which arose in the advanced society will face no obstacles (*e.g.*, government's ban, *etc.*) in other societies;
- the sector must have a great potential for the growth of its productivity and the need for the growth of productivity must remain high for a long time to stimulate the innovations and investments.

Let us consider these conclusions in the context of the Cybernetic Revolution. It is evident that the future breakthrough sector of the final phase of this revolution should have already developed. But which of the existing ones meets the mentioned characteristics? We argue that there will be no breakthrough, for example, in the field of green (low-carbon) energy sector (despite the fact that at present wind power demonstrates high growth rates) because green power will be unable to completely replace traditional energy resources but it will coexist with it just as hydro- and nuclear power coexist with carbon energy. We think that robotics could become the break through direction if there were created robots that could perform different functions in the services sector. Not without reason the future scientific and technological progress was thought to be connected with developments in the sphere of robotics. At present robotics finds wide application and is rapidly developing (see, *e.g.*, Makarov and Topcheev 2003; Gates 2007). But still one can hardly say that robotics will become the breakthrough direction judging by the current volume of investments in this sphere which grows slowly, and there are much less investments in the biotechnology field. However, it will play a very important part in the final phase of the Cybernetic Revolution and should achieve outstanding results though somewhat later, perhaps in the middle of the final phase of the Cybernetic Revolution or even at the end of it (see Conclusion).

On the basis of the analysis of the current situation one can conclude that the only field which meets all the requirements is medicine. That is why medicine will be the first sphere to start the final phase of the Cybernetic Revolution, but, later on, the development of self-regulating systems will cover the most diverse areas of production, services and life. We treat medicine in a broad sense, because it will include (and already actively includes) for its purposes a great number of other scientific-technological branches (*e.g.*, the use of robots in surgery and taking care of patients, information technologies in remote medicine, neural interfaces for treatment of mental illness and brain research; gene therapy and engineering, nanotechnologies for creation of artificial immunity and biochips which monitor an organism; new materials for growing artificial organs and many other things to become a powerful sector of economy).

Let us consider in detail why medicine is to become the breakthrough sphere.

a) Medicine is unique because it inspires constant activity in the field of new high technologies.

b) There are far fewer social, cultural or structural obstructions to the application of these technologies in medicine than in other fields (as well as the obstacles to adoption of innovations).

c) The commercial prospects of new technologies in this sphere are huge since people are always ready to pay for them.

d) In the nearest decades not only the developed but also developing countries will face the problems of population ageing, shortage of labor resources and the necessity to support a growing number of elderly people. The progress in medicine can contribute to the extension of working age (as well as to the general increase of the average life expectancy) of elderly people and to more active involvement of disabled people into labor activities. *Thus, elderly people and people with disabilities could more and more subsist for themselves.*

e) A rapid growth of the world middle class and population education level, especially in the developing countries (NIC 2012) is anticipated in the nearest decades and these two factors mean that there will be a sharp growth in the demand for health services.

f) The medical sphere has unique opportunities to combine the abovementioned technologies into a single complex. Many spheres (including but not limiting to biotechnologies, nanotechnologies, robotics, use of the latest ICTs and various devices, cognitive technologies, synthesis of new material) will be integrated in this field.[9]

[9] It should be noted that Leo Nefiodow has been writing about medicine as the leading technology of the Sixth Kondratieff Wave (according to his approach, this wave began in the end of the 1990s and will last until the 2050s) (Nefiodow 1996; Nefiodow and Nefiodow 2014a, 2014b). We do not agree with him about the date of the Sixth Kondratieff Wave, which, according to our estimates, will start in 2020s and will last until the 2060s (Grinin L. E. and Grinin A. L. 2014). Never-

Thus, given the general vector of scientific achievements and technological development and taking into account that a future breakthrough area is to be highly commercially attractive and have a wide market, we predict that the final phase of the Cybernetic Revolution will begin in medicine.

By the 2030s there can appear unique opportunities for a breakthrough in medicine:

– by that time we will face the problem of population ageing (by 2030 the number of people aged 65 and over will amount one billion (see Fig. 4). Moreover, this problem will be typical not only of the developed countries where it will become crucial for democracy, but also for a number of developing countries, in particular, China and India. Pension issues will become more acute (as the number of retirees per worker will increase) and at the same time a shortage of qualified labor force will increase (which is very critical in a number of countries, *e.g.*, in Russia). *Thus, we will have to solve the problem of labor force shortages and pension contributions by increasing the retirement age by 10 or 15 years (of course, it is necessary to solve complex social problems at first).* It also refers to the adaptation of people with disabilities for their full involvement in the working process due to new technologies and achievements of medicine;

– simultaneously by that time, the birth rates in many developing countries will significantly decrease. Therefore, the government will start to be concerned about the health of the national population and not about population control;

– by the 2030s great changes will occur in the opportunities of billions of citizens of the developing countries due to leveling of peripheral and developed countries, formation of a huge middle class, and reduction in poverty and illiteracy. As a result, the focus will be shifted from elimination of the most unbearable conditions to the problems of raising the standards of living, healthcare, *etc*. So, there is a great potential for the development of medicine.

However, primarily the breakthrough will not necessarily occur in all spheres of medicine but in its one or two innovative fields (similar, the final phase of Industrial Revolution occurred not in all branches of textile industry but in its innovative sector, namely in cotton industry). As for other branches of medicine, revolutionary transformations will begin there later. Moreover, some branches of medicine would be unable to transform due to their conservatism. Thus, more radical reforms will occur in these fields in the future. So when

theless, we generally support his ideas about the role of medicine (including the ideas about a new type of medicine), but it is important to point out that Nefiodow believes that it is biotechnologies that will become an integrated core of a new mode. However, we suppose that the leading role of biotechnologies will consist, first of all, in their ability to solve the major medical problems. That is why, it makes sense to speak about medicine as the core of new technological paradigm.

speaking about medicine, one should keep in mind that with respect to potential revolutionary transformations medicine is a very heterogeneous sphere.

However, in the process of the final phase of the Cybernetic Revolution and after its end the *development of medicine will follow the path of correction or even modification of our biological nature*. In other words, it will be possible to extend opportunities to alter a human body, perhaps, even its genome, to cultivate biological materials for regeneration, as well as to use artificial organs and tissues for it (for more detail see below).

Along with many other medical innovations (e.g., minimizing invasive operations) it will be possible to dramatically increase life expectancy and improve physiological abilities of people as well as health-related quality of life (HRQoL).

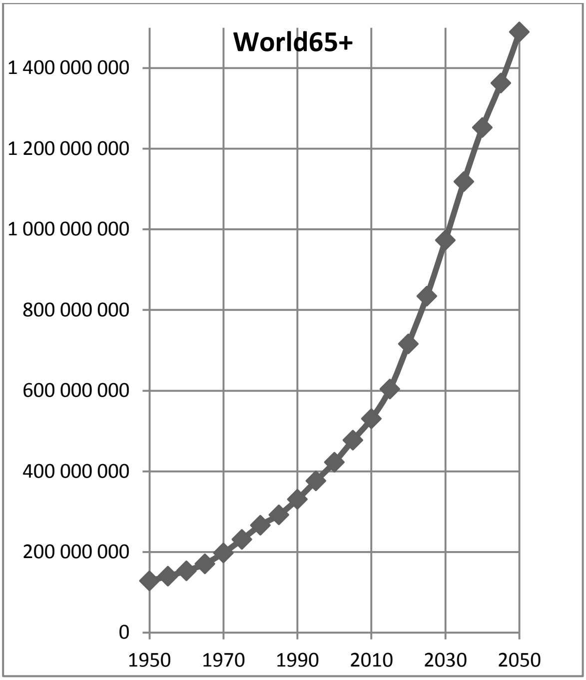

Fig. 4. Predictable increase in the number of people aged 65+, estimated for 1950–2015 and projected to 2050.

Source: UN Population Division 2015 (Grinin and Korotayev 2015b).

Medicine as a sphere of the initial technological breakthrough and the emergence of MBNRIC-technology complex. It is important to understand that even though the final phase of the Cybernetic Revolution will be connected with great transformations in the opportunities to influence the human health, life expectancy, quality of life, as well as human biology itself, the revolutionary changes will be much wider. Many spheres of production and life will be affected by these changes. They will include very many spheres of production and life. *On the whole, the final phase of the Cybernetic Revolution will result in the convergence of technologies and development of MBNRIC-technologies (i.e. of a complex of medicine, bio- and nanotechnologies, robotics, ICT, cognitive sciences). Together they will form a sophisticated system of self-regulating production.*

Section 2. MEDICINE IN THE CYBERNETIC REVOLUTION

We have no opportunity to describe the whole range of MBNRIC-technologies with the equal attention. So in this paper we will focus more on describing current and future transformations in medicine. With less scrupulousness we will analyze the future transformations in the fields of bio- and nanotechnologies. Unfortunately, robotics and other technologies of the final phase of the Cybernetic Revolution will be briefly described.

1. Medicine in the Initial and Modernization Phases of the Cybernetic Revolution

In the initial phase of the Cybernetic Revolution (the 1950–1990s) there was a rapid growth of medicine as an increasingly important service sector. *At the same time the growth of health services constituted the general process of a rapid increase in service sector, which became the leading sector in terms of GDP in developed countries.*

During this initial phase of the Cybernetic Revolution new directions of medicine emerged while those directions that had emerged earlier reached a certain level of maturity (among them are electroencephalography, electric shock therapy, transplantology, active use of electronics, laser and new methods of diagnostics such as ultrasound, *etc.*). Substantial progress has been achieved in the sphere of child mortality reduction, infertility treatment, gerontology, psychiatry, development of contraceptive methods, and transplantation of organs and the creation of artificial organs, gender reassignment surgery, *etc.* Sport medicine, space medicine and other directions in medicine appeared during this time. On the whole, due to medicine people learned about controlling their bodies and maximizing their health.

To better understand the breakthroughs which took place in medicine during the initial phase of the Cybernetic Revolution, it makes sense to refer to the most prestigious award in the field of science. In the period from the 1930 to the 1980s the authors of discoveries in the field of vitamins, hormones, antibiotics, nervous regulation, enzymes were awarded the Nobel Prize. All of these discoveries began to be used in pharmacology. After 1958 genome researchers were awarded the Nobel Prize.

Medicine in the modernization phase. The period from the 1990s till the present represents the modernization phase of the Cybernetic Revolution.

At this phase the major direction of medicine underwent dramatic changes. In the 19th and 20th centuries many fatal diseases were defeated (cholera, yellow fever, typhoid, tetanus, polio, whooping cough, measles, malaria, diphtheria, *etc.*). It would seem that fatal highly infectious diseases except for AIDS (which is widespread in African countries) have been defeated. At the initial phase of the Cybernetic Revolution the fundamental task was to increase the life expectancy. As a result, when the task was accomplished, the main concern of the last period of the initial phase and the modernization phase of the Cybernetic Revolution became the struggle against the diseases of aged people.

According to WHO, in 2012 the most frequent causes of death in the world were respiratory diseases – 6.2 million (14 per cent), ischaemic heart diseases – 7.4 million (11.1 percent), stroke – 6.7 million (11.9 per cent), HIV/AIDS – 1.5 million (2.7 per cent) (WHO 2014).

As a result of the Cybernetic Revolution the changes in the general trend in medicine led to the emergence of new pharmaceuticals. One of the peculiarities of contemporary medical development is a constantly increasing production of drugs. For example, in the USA, from 1950 to 2000, the number of firms producing drugs increased more than seven times (Demire and Mazzucato 2008). By 2006, the production of drugs doubled, and the total global market volume of drugs was estimated at US$ 640 billion, about half of which was accounted for in the USA (Kondratieff 2011). This field remains one of the most profitable fields with a sales profitability of 17 per cent (*Ibid*.). Every year the volume of consumed drugs increases by several percent. Over the last 15 years the revenue of the worldwide pharmaceutical market has increased more than twice.[10]

Now medicine is closely related to biotechnologies (through pharmaceuticals, gene technologies, new materials, *etc.*). The distinctive feature of modern medical science is its 'bio-related trends' – a wide use of approaches based on the methods of molecular and cell biology. Note that the growing importance of medicine is shown in the phenomenon of medicalization. It is expressed in the fact that many aspects of human behavior (especially deviant) and psyche which have never been related to medicine, start to be described in medical terms and require medical observation and intervention (see Yudin 2008).

The process of differentiation of medicine which started many years ago in many branches has intensified. At present there are about one hundred medical branches and relative scientific disciplines. Among others, nanomedicine, biomedicine, stem cell research and generative medicine are declared as formed branches (see Strategy… 2013; Wagner *et al*. 2006; Minger 2006). It is also

[10] See URL: http://www.statista.com/statistics/263102/pharmaceutical-market-worldwide-revenue-since-2001/

worth mentioning such new directions as shockwave therapy and control of cholesterol levels. The directions which emerged earlier have been actively developing, for example, those which are related to artificial fertilization, maintenance of pregnancy and obstetrics, *etc.*

At present medicine is highly computerized especially in the field of diagnostics, various automatic control systems have been developed; for example, for the control of breathing, nutrient supply to specific organs, blood pressure, control over the functioning of some internal organs, *etc.* A large range of drugs have been developed which over time decrease in price and become more available to the general public. Surgery connected with the transplantation of organs and the replacement of certain human organs by artificial organs, endoscopic surgery providing operations without incisions, and rehabilitation medicine are all developing rapidly. Surgical methods have become less invasive and require less time for rehabilitation.

The current stage is represented by the prevalence of innovations accumulated over the last decades since most of the latest technologies are based on improvements to previous discoveries and inventions. Starting with the 1980–1990s we observe considerable progress in the struggle against the most common causes of mortality – heart attacks, strokes, orphan diseases and other diseases including hereditary. Significant progress has been made in technologies for diagnosing internal organs and tissues using such methods as X-ray computed tomography, nuclear magnetic resonance introscopy, X-ray photography and others (Mirsky 2010: 19). At present the fastest developing fields of medicine (in its broad sense) are the fight against incurable diseases, implantations, reproductive medicine, gene therapy, pharmaceutics and aesthetic medicine which we will consider below.

On the whole, medicine (supported by both government and private funding) has been a major influence on GDP. The distribution of medical technologies is a very expensive process. Despite that cost, there still has been a steady increase in funds allocated to medicine by the state. Generally, its growth is comparable to the GDP growth rate. But in the developed countries spending on health care per capita is 10–20 times larger than in the developing countries. Taking into consideration the anticipated faster growth rates of GDP in the developing countries and a rapid formation of the middle class there, one can suppose that in general, spending on health care will increase significantly. Ageing of the population together with growing prosperity will lead to a situation where health care spending will outpace the general GDP growth. And this tendency is likely to increase.[11] It is not strange because in the developed coun-

[11] One can prove this by the fact that even in the periods of insignificant GDP growth, the expenses for health care increase very fast. In particular, in the OSCE countries in the period of the last crisis (2008) the growth of GDP per capita was very low – 3 per cent (correspondingly in 2007 – US$ 35,855, in 2010 – US$ 36,994), and expenses for health care per capita increased by 13 per

tries a significant part of population is involved in medicine. For example, in Germany a number of health care personnel constitute 22 per cent of the total number of employed people while the share of automobile industry is only 2.3 per cent (Nefiodow and Nefiodow 2014b). The level of medical development has significant impact on such popular development indicators as the human development index (HDI).

The development of aesthetic medicine. At present aesthetic and cosmetic medicines are vigorously developing and their main task is to correct defects or alterations which concern the person and improve attractiveness (eliminate wrinkles, provide attractive rejuvenation, different types of face lift, liposuction, body shaping, transplant hair, wide spread of already proven technologies, *etc.*). According to *Forbes*, the global cosmetic surgical and aesthetic medical market amounts to 180 billion dollars (Zhokhova 2011).

One of the highest achievements of plastic surgery is the face transplantation. The first full face transplant was performed in France in 2005 on a woman who was mauled by her dog. Recently, details of the most extensive face transplant performed in March 2012 were presented. The doctors from the University of Maryland Medical Center gave a new face including jaw, teeth and tongue, to 37-year old Richard Norris.

During the next two decades cosmetic and aesthetic medicines are supposed to rapidly develop (though it can cause rather serious psychological problems including those connected with individual's self-identification). This will be achieved through the emergence of new technologies, as well as the living standard growth in the developing countries. The wealthier a society, the more money people spend on health and beauty. Taking into account the growth of the world middle class, this direction and all types of aesthetic medicine are expected to develop rapidly. Once the new technologies based on the achievements of medicine and genetic engineering have been established, aesthetic medicine will be able to become the correction medicine of the future, one of the most important tasks of which will be to correct birth defects and acquired defects.

cent (correspondingly in 2007 – US$ 3,858, in 2010 – US$ 4,364) [calculated on the basis of World Bank 2012a]).

2. Forecasts Regarding Developments in Medicine. In What Way will the Characteristics of the Cybernetic Revolution Appear in the Development of the Medical Sphere?

2.1. Two decades before the beginning of the final phase of the Cybernetic Revolution

As we predict within the medical sphere some major innovations will reach maturity in two or three decades (some of them even earlier). Below we will consider some important trends of medicine.

Systemic problems of the Pharmaceutical industry. As we have already mentioned, at present the pharmaceutical industry has made considerable progress.

For example, we observe a rapid development of so called generics which are the drugs whose patent protection on the production is no longer valid. It is supposed that the global market of generics will double in the period from 2010 to 2018 and will reach US$ 230 billion. One can explain such a rapid growth by the fact that the vigorously growing economies of developing countries, like India and China, actively enter this market. Such growth is typical of the modernization phase of the production revolution as well as an opposite tendency which will be described below. In the securities market pharmaceutics also shows rapid growth (Williams 2014).

However, the number of serious systemic problems in pharmaceutics is increasing. In particular, in the recent decade there is a reduction in the amount of officially approved biopharmaceuticals protected by patent. On the other hand, a number of clinical trials of drugs steadily increase (Woollett 2012). Despite the rapid growth of capitalization at the markets of bio-technological (pharmaceutical) corporations in 2013–2015 which resembles a rapid growth of capitalization of IT corporations in the 1990s, the innovation process is slowing down. Many observers note that the expenditures on the new drug development are reduced because corporations have to spend from 1.5 to 3 billion dollars for new drug development and the drug development together with testing takes from 10 to 17 years. Therefore, the number of principally new drugs is not only increasing but on the contrary, decreasing, there are no breakthrough inventions (*e.g.*, Saigitov 2015; Martyushev-Poklad 2015). One of the important reasons of reducing production of biostimulators is strengthening control over their production. And most likely the problem of accelerated production of safe drugs will aggravate in the nearest decades; the solution of this problem can become an impetus for a breakthrough.

It is obvious that mass-market drugs have an important disadvantage: its efficiency is decreasing and really help only some part of patients (from 30 to 50 per cent). The growth of pharmaceutical production is connected with unification which leads to decreasing efficiency as even well-investigated diseases often proceed individually. *Prescribing faults also cause serious side effects. For example, according to some data (probably, overestimated), in the period from the late 1990s to early 2000s, prescribing faults annually* caused more than 100,000 deaths (Null *et al.* 2003: Table 1).

The theory of production revolutions can provide a general explanation of such innovation slowdown in pharmaceutics. The main vector of the modernization phase of the Cybernetic Revolution is a wide dissemination of innovations which have already emerged (in the first stage), their modification and synthesis. Therefore, there can be fewer basic innovations in this period in certain directions than in the previous period (yet they are much more widespread). Besides, the increasing scale of the production revolution causes an intensification of the struggle between 'conservatives' and 'innovators' with respect to the implementation of innovations, for example in the field of drug control (as well as in the field of distribution of GMO and other innovations such as cloning, *etc.*).[12] In such situations it is rather difficult to say who is right: 'conservatives' or 'innovators'. On the whole, such discussions contribute to the search for optimal paths towards progress. On the other hand, one can suppose that in the nearest decades there will be a new burst of innovations and creation of new age cures. At present we observe some attempts to find new directions in the field of pharmaceutics.

Obviously, in the work of pharmaceutical firms lacks such an important characteristic of the Cybernetic Revolution as individualization. It is quite obvious since the considerable expenses for the development of new drugs require huge market for their distribution.

However, there are some precursors of the strategy changing towards individualization. For example, let us consider Christopher Wasden and Brian Williams' model. Pointing to such difficulties as lower reimbursement rates, diminished pools of venture capital, the advent of personalized care and a growing demand for improved patient outcomes, they consider them as a precursor to a hurricane that will batter unprepared companies and fundamentally change how healthcare is delivered and evaluated (Wasden and Williams 2012: 2).

These representatives of innovative business offer a new model in pharmaceutical and medical business which is named as 'Owning the disease: A new transformational business model for healthcare'. Their suggestions are based on the experience of IT companies and they propose to turn to consumer-centric disease solutions rather than the traditional R&D department approaches) (*Ibid.*).

[12] Here one can make an analogy with a situation in the 17th – 18th centuries when different craft restrictions stood in the way of technological progress (and the technological progress bypassed these restrictions). That is why one can suppose that a brand new breakthrough can follow a different pattern.

The basic idea of this model is to combine the opportunity to solve the tasks and problems related to diagnostics and treatment of a certain disease. In other words, the patient gets the full range of services to solve health problems connected with the real (or potential) disease.

> Medical technology companies are changing their focus in three important ways, shifting from selling features to providing solutions; from focusing on silos to a broader systems approach; and from generating profits by increasing volume to winning by delivering greater value. In turn, these strategies are transforming the fundamental business model of medical device manufacturers, resulting in them taking a more comprehensive approach to their business that compels them to seek to 'own' the diseases or conditions their products are intended to treat. Owning the disease should not be confused with disease management, the early iterations of which evolved during the heyday of managed care but which lacked the connectivity and incentives to effectively understand, monitor, influence, and change patient behavior, as well as support care coordination or overcome the cultural divide between payers and providers (*Ibid.*: 7).

This approach takes account of such important tendencies of the forthcoming Cybernetic Revolution (which have been mentioned above) as resources saving (according to the authors of the project, the systemic approach allows reducing expenses) and individualization. The clients of medical companies insist on a personalized approach and on the correlation between the payment for treatment and its results but not the number of manipulations. As the company will be paid for the results of the treatment and not for the treatment process, it will be interested in avoiding the treatment and searching for the prevention measures and optimal solutions.

The authors of this work believe that the company which will be able to create a platform for 'mastering the disease', will have many strategic advantages over the competitors.

However, the conservatism of the present pharmaceutical and medical institutions and huge financial interests of very influential forces behind them will certainly obstruct such a transition.

The struggle against incurable diseases, as it was said, is the most important direction of medicine. In general, mortality from cancer in developed countries reaches the same level of mortality as does coronary artery disease.

With the rapid ageing of population the potential danger of age-related diseases will increase. The present tendency is that with growing life expectancy cancer diseases take first place among diseases. Therefore, the most significant task of medicine will be the struggle against cancer and other age-related diseases. Nowadays incurable diseases are the challenge for humanity. It is not surprising that big awards are provided for solutions to these problems.

In the context of the struggle against cancer there are some positive changes connected with the possibility of early diagnosis and increasing percentage of cured people (see below) but the situation has not changed dramatically. It is possible that cancer will not be defeated by the 2030s. Apparently, cancer treatment requires considerable changes. If we defeat this disease, there will appear a strong impetus for a breakthrough in medicine and its transition to a completely new level.

Movement towards self-regulating systems and minimization of interference. We observe the growing controllability of systems in different branches of medicine. Some of them have already reached the stage of real self-regulation. For example, life support systems or artificial organs. Other systems are moving towards self-regulation and they are intrinsically linked to the minimization of traumatization of a patient. For example, in surgery a lot of flexible instruments are used allowing the doctor to be able to perform surgery on the most inaccessible parts of human body with minimal incision. These operations are conducted with the help of endoscopes and video cameras transmitting an enlarged image on the monitor. In order to solve the problem of hand tremor special robots are used to substitute for human hands. Operating such a device, a surgeon controls the smallest movements of the instrument (including the laser, or ultrasound). One can anticipate that in the nearest future a lot of operations will be conducted without human surgeon's participation.

Robots in surgery. Surgical robots is a rapidly developing sector. There were only 1000 surgical robots in 2000 around the world. In 2011 they already amounted to 360000, in 2012–450000 (Pinkerton 2013). Since 2000, about 1370 clinics of the USA ordered robots, which average price is about 2 million dollars for one robot (Beck 2013). Robots-surgeons are classified as: assistance functions robots, telesurgical instruments, navigation system, robots for precise positioning, robots for specific surgery tasks (Taylor 1997)

According to the research data conducted by the Columbia University from 2007 to 2010, in the clinics of the USA robots performed from 10 to 30 per cent of surgical operations (*Ibid.*). The surgical operations involving robots' participation have a lot of advantages. The surgical robot DaVinci is mostly widespread.

It is a big machine which is equipped with flexible ‘hands’ – manipulators with a set of surgical tools. A very small incision is made to the patient, therefore surgical operations are not so painful and demand the smaller period of recovery. Robots allow to use all the latest tele-video systems which help doctors to see clearly the operation process much enlarged and in color. The doctor watches the monitor and controls the robot, sitting in the other part of the surgery (in future he can also be in any other city or even country), the assistant watches the robot and the patient. For the purpose of watching the surgery process in full detail HD 3D screens are installed for the patients. Surgeries involving robots' participation are becoming very popular, for example, the medical companies in the USA use the billboards for attracting more clients to these painless fast procedures (Pinkerton 2013).

However, along with the advantages, surgical robots cause serious fears. The doctors from Rush University Medical Center, the University of Illinois and the Massachusetts Institute of Technology provided the data according to which the strong increase in the cases of injuries and fatalities after the operations performed by the robots is observed, from 13,3 cases per 100 000 surgical operations in 2004 to 50 cases in 2012 (*Ibid.*). FDA registered an increase of 34 per cent of the deaths from surgical operations involving robots in 2013, relative to the previous year (*Ibid.*). In 2013 Massachusetts health officials sent an advisory to the state's hospitals urging caution, 'As with any new technology, care should be taken that protocols are in place to ensure appropriate patient selection and the full explanation of risks and benefits for all surgical options' (*Ibid.*). The cost of surgical operations involving robots is higher as compared to the ordinary types of surgery and in the USA varies from US$ 30,000 to 50,000. The price of Da Vinci starts from one million dollars. However, in view of significant economy at a recovery stage, it is possible to predict that clinics will prefer to buy robots for the long-term economy and customer engagement (*Ibid.*). Substantial savings can be realized on the skilled work of surgeons. Many clinics may not have the leading surgeons, they will be able to use services of online surgical operations conducted by the leading experts hands.

2.2. The social-economic premises for a breakthrough

As we have mentioned, the field of some innovative branches of medicine will be the sector where the final phase of the Cybernetic Revolution will start and develop. The unfolding situation will arise by the 2030s in the growth of the economy, demography, culture, living standard, *etc.*, will contribute to this. And this will determine a tremendous need for a scientific and technological breakthrough. On the whole, these successful conditions will entail major investments in medicine: increase in the number of well-off and educated people and middle-aged and elderly people (who particularly are willing to actively spend money on medicine), strengthening of the need for extra labor force and interest of the state in improving the working capacity of elderly people. In other words, the conditions for activization of business, science and state in order to provide a breakthrough in the field of medicine can be unique and *the formation of such unique conditions is necessary for the beginning of a new phase of the Revolution!*

One more prerequisite for the beginning of the final phase of the Cybernetic Revolution in the 2030s will become remote medical care which will be well developed by this time and due to which there will also be a leveling of conditions for patients. It means that the quality of medical care services will not be so highly dependent on the qualifications of medical personnel in a particular medical care unit. Even now we are witnessing this process, thus we can say that it will be very strong in the nearest decades and in the beginning of the final phase of Cybernetic Revolution.

3. The Shifts during the Final Phase of the Cybernetic Revolution

3.1. The developing characteristics of the Cybernetic Revolution

Preliminary ideas about the forthcoming changes in medicine. As we have already mentioned the transition to the final phase of the Cybernetic Revolution will begin in some field of new medicine (which could be closely related to some other innovative technologies) and then step by step will affect other fields. In particular these revolutionary changes will be connected with the formation of systems for monitoring health, supporting the organism and treatment will be performed mainly by the autonomous systems which will be able to function regularly and constantly.

Medicine will also develop in the direction of: a) prevention and propedeutics of diseases; b) controlling the processes of life and elimination of irregularities; and c) maximal account of individual characteristics.

Self-regulation and controllability of systems is manifested in many branches of medicine, for example in the situation when treatment, operations and further rehabilitation will be under a fuller control of self-regulating systems. In the future it will be possible to provide certain treatments through special devices, systems, robots, *etc.* It is one of the most important directions which will be realized during the 2030–2050s.

Emergence of robots also shows the transition to self-regulating systems. The scientists from the Oslo University in Norway by means of 3D-printing invented the self-learning robots which also have 3D printers in their structure and are capable to print the necessary detail (Howell O'Neill 2014). The RoboEarth project is very interesting, *i.e.* it is the Internet for robots in which they record all their operations and can address it if the necessary operation is absent in the installed program. It is the beginning of the collective intelligence of robots (Waibel *et al.* 2011).

Another manifestation of self-regulation will consist in the technological control of processes of human organs (through necessary albuminous compounds, cells, antibodies, activization of immune system, *etc.*). In other words, treatment will become more targeted.[13] The drug delivery systems will change dramatically. Nanotechnology, particularly nanotubes, will probably play the key role in it.

[13] One of the contemporary optogenetic technologies provides a good example as well as a general idea of how this can work. The essence of the technology is that the DNA fragment which codes for special membrane proteins is integrated into the genome. These light-activated proteins (from the light-source implanted in the brain tissue or through transosseous luminescence) can create an ion flow inside the cell and thus, lead to its activation (Saigitov 2015).

The radical transformations in medicine will dramatically change the position of a doctor. Which technological innovations will cause such transformations?

At present the tests for important indices can be made without doctors by means of special devices and testers (see, *e.g.*, the chapter about the antibodies). On the basis of the test results one can define the norm and abnormalities. For example, in order to remotely control the patients, the company Applied Digital Solutions developed the device 'Digital Angel' equipped with the self-rechargeable energy. This tiny biochip measures the biological parameters of the body. It is unlikely that such devices will appear in the very near future. Nevertheless, the emergence of such forecasts is quite remarkable as they show the movement towards the development of self-regulating systems.

Due to such technologies a number of functions of a doctor can be performed by the patients. Perhaps, in the near future diagnostics will be transferred to mobile devices on the basis of biochips which do not require the specialists' participation. Already now the centers of the best practice (Centers of Excellence) are developing, *i.e.* the places from where the leading doctors will be performing the operations and consulting the colleagues online (Binder *et al.* 2004). Thus, the profession of a doctor in its current form can lose a number of its present attributes. At present such a metamorphosis occurs in service sector (such as photo service, type setting and page makeup, design, selection of interior, purchase of tourist vouchers, selection of routes, *etc.*). Of course, the profession of a doctor will exist but the number of doctors probably will not grow and in the end of the final phase of the Cybernetic Revolution its number will even decrease. Such systems as health monitoring system described below will also affect the positions of a doctor.

Constant health monitoring as a self-regulating supersystem. Nowadays the boundary between medical diagnosis and treatment already becomes more and more imperceptible. Diagnostics is a constant necessary measure for disease controlling and drug dosage. During the final phase of the Cybernetic Revolution there will start a breakthrough in all fields of medical care. Thus, very important direction of self-regulation can be associated with the development of the health monitoring system that will allow early diagnosis and preventing diseases. The key compounds of such devices are biosensors.[14]

One can easily imagine that in the future biosensors will be able to become an integral part of human life fulfilling the function of a constant scanner of the organism or of certain organs and even transmitting the information about it to medical centers in case of potential threats or serious deterioration in the state of health. Built-in sensors will allow for controlling and regulating all vital pro-

[14] Biosensors are electronic registering devices which use biological material such as enzymes, cells and antibodies (for more detail see in the paragraph about biotechnologies).

cesses, as well as prompting the time of drug intake and their dosage, time of physical activities and required exercises with the account of different circumstances, and recommending the most appropriate diet, *etc.* Thus, smart computer systems will be able to monitor significant fluctuations of indicators and give recommendations about short- and long-term living habits.

What will these innovations bring: will the consequences be good or bad? Of course, people's free agency will be restricted as well as it is possible that they will get used to obey machines and in some measure lose ability to decide by themselves. At the same time, certain imperatives with respect to health will be formed.

Respectively, such mini-systems can be integrated into a large system which monitors a large number of people, for example in medical centers, therapeutic facilities, hotels, *etc.* We have already mentioned the decreasing number of hospitals, and such monitoring and remote online access can significantly relieve hospitals. One can imagine that such systems will be able to detect potentially dangerous situations and quickly respond to critical situations. That is a good example of prognostics and prevention of problems. We suppose that it will take much time to create such systems. Besides, there are complicated ethical and legal problems as regards to such monitoring as there always exists the danger that a watching 'Big Brother' will take advantage of this.

Economy and optimization of resource consumption. The achievements in medicine will make a significant contribution to *the optimization of resource consumption*: first, it will increase life expectancy (which is the most valuable resource); and, second, it will increase human health and thus productivity. Optimization of resource consumption will be expressed, for example, in the drugs economy due to the targeted delivery and minimization of interference with the organism. Hospital treatment will be less used as the operations will be more targeted, and the rehabilitation period will be minimal. More people will be treated at home since the development of remote treatment is rather probable when doctors control the indices of a patient online and can make the necessary prescriptions remotely. It could sharply decrease a cost of medical treatment which now is exorbitant one for a great number of people. Saving money (as well as resources) is one of the most important directions for the economy.

Medicine develops in the direction of growing **miniaturization (as one of the economy).** We think that with respect to medicine we can use the term 'miniaturization' in two senses. One is the common one– as a trend of constantly decreasing size of instruments to micro and nano size (Peercy 2000). The second one is a trend of constantly decreasing the zone of medical intervention on human organism. For instance, during surgery contact is focused only on the target epidermis layers. For example, some eye operations with the use of laser are aimed at removing tissues only a few microns thick. Such operations require no subsequent rehabilitation.

3.2. The forecasts of the development of some medical technologies

Artificial antibodies and the growth of opportunities to use the immune system. There will never be any universal drug against all diseases. But strengthening the immune system is one of the universal directions which can transform this situation and help the struggle against different diseases. Everyone has his own protective system based on the 'history of diseases'. It is one of the most important directions of development of **individualization**.[15] Medicine is always connected with a patient's individuality. However, in the twentieth century there was a tendency towards mass medicine (connected with mass vaccination, preventive examinations, *etc.*). At present there are some signs of transition from mass medicine to individual medicine (in particular, in aesthetic medicine), which is related to the general tendency of the Cybernetic Revolution towards individualization. But individualization to an even greater extent will be manifested when based on the unique characteristics of the organism, one of which is the immune system.

One of the main ways to create an artificial immune system is to produce artificial antibodies. Antibodies are the molecules synthesized to fight against certain cells of foreign origin – antigens.

Scientists have repeatedly attempted to produce artificial antibodies. Various methods were used, the most widespread method was isolating antibodies from the blood of animals but the degree of purification remained low. In 1970, Cesar Milstein and Georges Köhler found the method of producing the antibodies of a certain type, that is of monoclonal antibodies. In 1984, they were awarded the Nobel Prize for this discovery. Nowadays a focus of much medical research is into the production of antibodies by other means (Schirhagl *et al.* 2012) and also the creation of chemoreceptors (Dickert *et al.* 2001). Antibodies have already become widely used in pregnancy tests, in the diagnostics of many diseases, in laboratory experiments.

We suppose that during the final phase of the Cybernetic Revolution there will be considerable progress in the creation of artificial antibodies and their acceptance by the organism. The formation of artificial antibodies will play an important role in the prevention and treatment of many serious diseases, they will prevent the rejection of transplanted organs, *etc.* This will help make controlling the course of a disease easier and will help in suppressing the disease and defeating the disease if it is possible. Progress towards the creation and acceptance level of artificial antibodies will mean a significant growth of *opportunities to control processes previously inaccessible for controllable interference and appearing of self-regulating systems for regulation of such interference.*

[15] Here the notion of individualization refers not to every antibody but to the artificial antibodies specifically created by each individual organism.

Control of programmed cell death (*apoptosis*) is one of the promising methods to defeat serious diseases including cancer. The researches into this field have been carried out from the 1960s. They show that some cells often die in strict compliance with the predetermined plan. Thus, the microscopic worm nematode's embryo consists of 1090 cells before hatching but later some of them die and there remain only 959 cells in the adult worm organism (Raff 1998; Ridley 1996). The mechanism of apoptosis is associated with the activity of signaling molecules and special receptors which receive the signal, launch the processes of morphological and biochemical changes, and as a result lead to the cell death.

An opportunity to trigger the self-destruction of the cells provoking the diseases can make the struggle against diseases controllable. Besides, it provides a rapid recovery without long period of rehabilitation which is necessary after surgical intervention, chemotherapy or radiation treatment (it is the example of economy of energy and time for a patient). Also switching off the mechanism of cell self-destruction will help to save an organism from some diseases and, probably, to control the process of ageing. We suppose that during the final phase of the Cybernetic Revolution medicine will be able to make progress in this direction and in the mature stages of the scientific-cybernetic principle of production to control it. In this case similar to the artificial antibodies and the systems of immune production (see about it below) the movement towards creation of self-regulating systems will occur on the basis of the influence on the key elements of these subsystems of the organism in order to select the optimal regime in the context of certain goals and tasks. So in some cases it will be possible to evoke the death of unwanted cells deliberately and in other cases to block the mechanism of death of necessary cells.

Breakthroughs in the field of control of human body. Transplantation: on the way to biotechnical systems of the highest level. Another important direction of medicine is connected with the regeneration and transplantation of organs and parts of the human body. At present such operations are already performed, for example, heart, lungs, liver, pancreas, and kidneys are now transplanted. However, human donor organs are scarce, and people who distribute donor organs without special agreement are brought to criminal responsibility all over the world. The solution to the problem of shortage of organs is carried out in different directions:

1. Use of a part of a donor organ and growing a new organ using stem cells.

2. The possibility of xenotransplantation (transplantation of animal organs into humans).

3. The development of different organ substitution technologies such as 3D printers (the most promising direction).

Besides, in medicine scientists already use or work to design different artificial organs: skin, retina, trachea, vessels, heart, ear, eye, limbs, liver, lungs, pancreas, bladder, ovaries. Even combination of the above-mentioned opportunities is rather possible. There is already an opportunity of tissue engineering. In laboratories they cultivate healthy skin or cartilage cells to replace injured bone or cartilage.[16] The potential of this technology is the formation of cell therapy and methods to regenerate tissues.

A breakthrough in medicine has become the development of artificial cornea by the scientists of Stanford University (USA). Such a great achievement became possible due to joint researches in the field of chemistry, nanotechnologies, biology and medicine (which are typical of complex technologies of the Cybernetic Revolution).

We can forecast that the finding of the opportunity to 'deceive' the mechanism of immune suppression of foreign cells will be the breakthrough in the field of regenerating and transplanting organs and tissues (see above). Already some steps have been made in this direction. Here one can also point to the opportunity to control processes by affecting the key elements of initial subsystem of human organism, in this case switching off the most vigilant systems of immune protection (just like anesthesia during a surgical procedure). The important event was when Japanese scientists discovered a way to reprogram the functions of cells. For example, the skin cells were reprogrammed and substituted for the damaged cells of an eye. Such kind of cells are not rejected, so this direction is exceptionally promising (Kostina 2013).

Neural interfaces. The technologies creating the interaction between an individual's nervous system and external devices are called neural interfaces (Brain-Computer Interface). They implement the interaction between brain and computer systems that can be realized via electrode contact with head skin or via electrodes implanted into brain. The implementation of neural interfaces is already wide-spread. They have developed neural interfaces that allow prosthetic devices to be moved via brain signals. Today, there have been developed scanning techniques to study brain signals. This gives an opportunity to reproduce any brain response.

At present there already exist devices which allow paralyzed people to speak, write and even work at the computer as, for example, in the case of the famous astrophysicist, Stephen Hawking. The neurosurgeons from the University of Pittsburgh School of Medicine performed a miracle when they implanted a chip in Tim Hemmes's brain. Being paralyzed, he can move a bionic prosthesis with his mind. The prosthesis has a special computer which conducts the

[16] Having grown a sufficient number of cells, these cells are implanted in the developed materials on the basis of polysaccharides and special substrates which control this growth. The growth conditions of the cells in these structures are very similar to their natural environment.

neural impulses from the brain to the specified action (Pylyshyn 2003). Global media actively discussed the news about the attaching of the electrical prosthesis by Italian and Swedish surgeons to a 22-years old drummer Robin Ekestam who lost his arm as a result of cancer.

However, despite the fact that neural interfaces show impressive results, their implementation is connected with many difficulties. For instance, many nanostructures and nanotubes are quite toxic for cells (Kotov *et al.* 2009). Implanting external devices leads to the traumatizing an organism despite the availability of many methods of mitigating the traumatizing effect (Grill, Norman, and Bellamkonda 2009). Another problem is the different electrical conductivity of biological tissue and the technical device. Probably, new nanostructures from which nanofibers for neural interfaces are made, can solve this problem (Abidian and Martin 2009).

Gene therapy is an advanced means of correction of an organism. Gene therapy constitutes a separate direction in modern medicine. A significant contribution to its development has been made by the Human Genome Project, whose aim is to determine the sequence of human DNA (Brown 2000; Stein 2004). However, the path from defining the structure of the genome to understanding its functions is long and this scientific discipline is at the very beginning of its development. The leading countries spend billions of dollars on the researches in the field of gene therapy.

Gene therapy combines a whole range of characteristics of the Cybernetic Revolution including expanding opportunities for *choosing optimum regimes in the context of certain goals and tasks*. Historically gene therapy was aimed at treating hereditary genetic disorders. But at present gene therapy is already considered as a potentially universal approach to the treatment of a wide range of diseases from genetic to infectious ones.

There are two approaches to gene therapy: *fetal gene therapy* when foreign DNA is introduced into the zygote (fertilized egg) or a germ at the early stage of development; thus, it is expected that introduced material will be inherited. The second approach is *somatic gene therapy* when the genetic material is introduced only in somatic (that is non-germinal) cells and it is not transferred to sex cells.

There is another approach – activization of organism's own genes for the sake of full or partial overcoming the impact of the mutated gene. The striking example of such approach is the usage of hydroxyurea for the activation of the synthesis of fetal hemoglobin in patients with sickle-cell anemia and thalassemia.

Gene therapy can become the example of individualization of the technologies and targeted influence on the processes. On the basis of the genetic data the most appropriate treatment will be adapted for individual patients, and if it is necessary the defective genes will be corrected. Presumably, gene therapy will manifest itself first of all in sports medicine as, first, it can become a new tool in the attempts of the pharmaceutical companies to avoid the control of anti-doping committee and, second, inherent potentialities become insufficient for achieving the best results in big-time sports.

When choosing the appearance of a future child (color of eyes, skin, *etc.*) gene therapy can be used. In future it might be possible that babies will be born almost by order, these will be 'the perfect babies' (Fukuyama 2002 with cite McGee 1997).[17] In other words, that means that parents will choose desirable features of a child before his birth. So, the geneticists will probably find 'the genes' of such qualities as nobility, aggression or unselfishness and even intelligence and due to this there will be created an 'improved' baby. Such genetic improvement will remind the improvement of face and body by plastic surgery methods. In other words, it will be impossible to make a genius or a champion of any child but it is not excluded that it will be possible to improve his potentialities. Just like at present it is possible to improve the sports and intellectual potentialities via special methods.

Presumably, first gene therapy will manifest itself in sport medicine as enormous investments are made in it and the best minds are engaged in this field (*e.g.*, the average annual salary of a physician in sports medicine is about US$ 200,000). Second, it can become a new method in the struggle of pharmaceutical companies against anti-doping committee. Third, increasing of sportsmen abilities is in great demand in professional sport as innate potentialities are no longer enough to set the record.

Changing human reproductive capabilities is an especially important field of medicine. The number of incurable diseases causing infertility decreases. Nevertheless, the only opportunity for some patients is to use *in vitro* fertilization. Besides, due to the development of medicine there increases a number of women who want to have children after their reproductive age is over (*e.g.*, Annegret Raunigk, a 65-year-old woman from Germany gave birth to quadruplets [Q13Fox 2015]). One should mention the technologies of growing an embryo outside the woman's body. The transplantation of reproductive organs becomes possible.[18] The scientists are developing the artificial womb which can be transplanted to a woman with the damaged womb or even to a man that will radically change the concept of sex (McKie 2002) and will cause new ethical problems. Artificial womb experiments have been successfully conducted

[17] It is difficult to say how 'perfect' they will be and what kind of problems will appear as a result of these technologies. For example, the possibility to predict the baby's gender resulted in gender imbalance in China. As a result, there are a disproportionate number of boys. Thus, we agree with Francis Fukuyama, who believes that the future achievements of the 'biotechnology revolution' should be accepted with great prudence (Fukuyama 2002).

[18] See http://www.theguardian.com/science/2014/oct/04/woman-gives-birth-womb-transplant-medical-first.

in Italy where artificial womb was grown and transplanted to a woman. In our opinion as a result of the final phase of the Cybernetic Revolution the number of the experiments with artificial fertilization will increase and growing of embryo outside the woman's body will become the reality.

The perspective direction in medicine is slowing down the ageing process. It was very difficult to find the scientific foundation of this process but finally it probably became tangible after the invention of the genetic structure of special bodies of the cells which are necessary for division – telomeres. It appeared that every time after the duplication of chromosomes a number of telomeres at its ends decreases. That is one of the reasons why cells are getting old and die when an organism reaches certain age. Perhaps, that is why our bodies get older, though hot debates among the scientists about this issue still take place (Slagboom *et al.* 1994). In 2009, Elizabeth H. Blackburn, Carol W. Greider and Jack Szostak were awarded the Nobel Prize in Physiology or Medicine for the discovery of the way chromosomes are protected by telomeres and the enzyme telomerase from terminal underreplication.

It is probable that genetic methods can significantly increase life expectancy. At present we observe the dynamics of increasing life expectancy, when the average life expectancy in some countries is more than 80 years. In our opinion, it will increase. Fig. 5 shows the dynamics of growth rate of persons aged 80 years or over until 2070. It will be even in the case of inertial prognosis. In fact in the end of the final phase of the Cybernetic Revolution the number of people 80+ can increase.

In the modernization phase of the Cybernetic Revolution the increase of life expectancy will be the largest in developing and medium-developed countries where life expectancy is significantly lower than in developed countries. There will be no significant increase of life expectancy in developed countries. The breakthrough in the field of medical technologies will occur a little bit later, as we have already said, in the 2030–2050s. Then, probably, there will be a new breakthrough in increasing the life expectancy; perhaps, it will increase by 5–15 years. The increase of life expectancy and especially preserving the quality of life and the individuals' activity for as long as possible in the context of the abovementioned characteristics of the revolution of the controllable systems means a further development of controllable systems, individualization, selection of optimum regimes, huge energy saving (including emotional) and unique experience and world perception. Every person gains invaluable life experience during his lifetime. One can also mention that it is an opportunity to preserve the previous generations' experience (under the conditions of rapid technological development and as a result the inevitable rejection of experience and knowledge accumulated by previous generations) at the expense of the personal experience of long-livers and personal contact of their descendants with them.

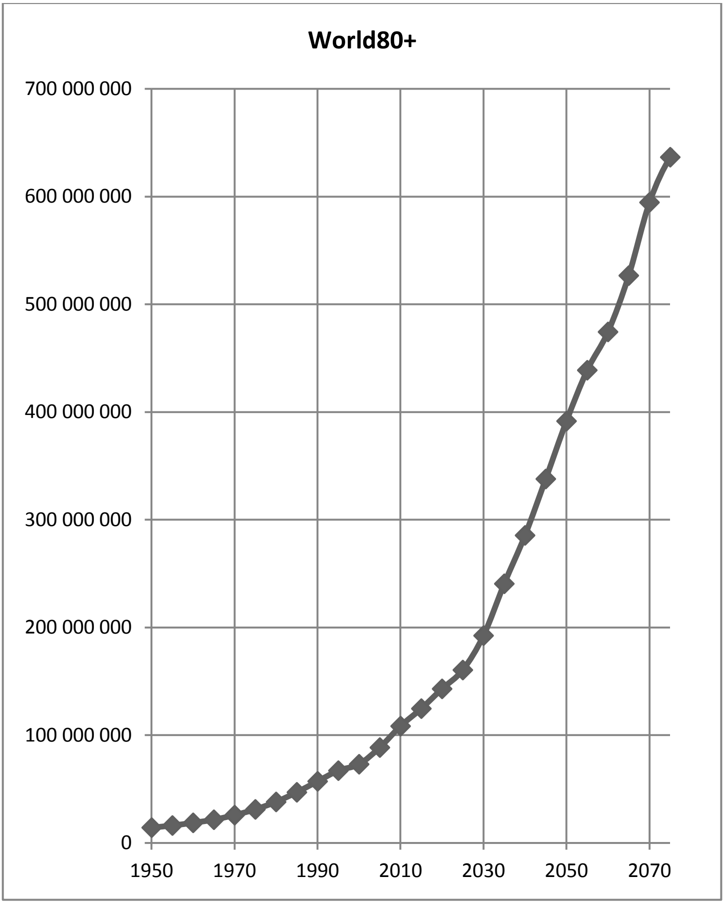

Fig. 5. Predictable increase in the number of people aged 80+, estimated for 1950–2015 and projected to 2075.

Source: UN Population Division 2015 (Grinin and Korotayev 2015b).

3.3. Will the development of the Cybernetic Revolution proceed in the direction of cyborgization?

A very popular word 'cyborg' (short for 'cybernetic organism') derives from the word 'cybernetic'. Cyborg is defined as a theoretical or fictional being with both organic and biomechatronic parts.[19] The term 'cyborg' often applied to an organism that has restored function or enhanced abilities due to

[19] The term was coined in 1960 by Manfred Clynes and Nathan S. Kline (Halacy 1965).

the integration of some artificial component or technology that relies on some sort of feedback.[20]

It is obviously that many achievements in medicine will impell our civilization to the state in which more and more humans can become partial cyborgs. Thus, we are following the path of development of self-regulating systems of a new type which will be constituted by the elements of different origin: biological and artificial. All that we have written about artificial organs and tissues will contribute to the breakthrough in the field of both production of absolutely new materials which will expand the implementation of non-biological elements in the human body. Thus, the Cybernetic Revolution is closely connected with the process that can be designated as cyborgization. We should be aware of the fact that this actually means not only the formation of a new direction in medicine, but also the moving towards the **cyborgization** of a human being.

Of course, this can cause a certain and quite reasonable anxiety. On the other hand, expanding the opportunities for not just a long but also an active life is hardly possible without significant support for the sensory organs and other parts of the body which weaken as a result of ageing and other reasons. Finally, glasses or contact lenses, artificial teeth, tooth fillings, bones, aerophones, artificial blood vessels, mitral valves, *etc.* allow hundreds of millions of people to live and work and these people still remain humans. The same is true with respect to more complex systems and functions. Thus, people with disabilities can benefit from the development of medicine and cyborgization as they will be able to significantly compensate their drawbacks.

However, we suppose that the idea that some day the human body will be fully replaced by non-biological material and only the brain or the organs which support the senses will remain are just fantasy. This will never come true (the well-known ideas about such future for humankind are presented by Kurzweil [1999]; see about such fantasies also in Rybalkina 2005: 333). People who propose such solutions, for example, to replace supposedly less lasting and comfortable biological material by the technological inventions (such as replacement of haematocytes by billions of nanorobots, *etc.*) in their forecasts try to use the outdated logic that was widespread several decades ago in science fiction or scary stories: the replacement of biological organisms with technical ones. The modern logic of scientific and technological progress including the latest achievements in bioengineering shows the movement towards the synthesis of biological forms and technical solutions into a unified system. Technical achievements can hardly replace the biological mechanisms which have been selected for many millions of years. On the contrary, we should follow the path of 'repair', improvement, the development of self-regulation and support of biological mechanisms via some technical solutions.

[20] URL: https://en.wikipedia.org/wiki/Cyborg.

The human brain is very tightly connected with the body and sensory organs, most of its functions are based on the control of the body that does not imply its full-fledged work outside its biological foundation. The opportunities of science and medicine to replace worn organs will increase but the biological foundations of a human will always exist and must prevail. If one can help the human body by different means including methods of activization of immune system, opportunities of genetics, the methods of blocking or decelerating the process of ageing, *etc.*, it is much more reasonable to preserve the human biological foundation. In any case, in the nearest decades in the process of cyborgization quite radical breakthroughs are possible, but nevertheless the process of cyborgization will not go too far.

Improvement of individuals' natural abilities. It is important to note that at present all these technologies aim at restoring individual's lost functions. It does not exclude the future possibility that this direction will provide opportunity to move towards improvement of natural and intellectual abilities beyond the natural bounds. However, in fact this can hardly happen by the end of the 21st century. Probably, the process will be similar to the process in the field of plastic surgery which was first created for the repair of damaged tissues but then it became the beauty industry.

Section 3. FORECASTS: BIOTECHNOLOGIES IN CYBERNETIC REVOLUTION

Definition. Biotechnology is a broad and multifaceted notion. Until the 1970s the term 'biotechnology' was used mainly for the description of some technological processes in food industry and agriculture. After in laboratories they started using recombinant DNA and cell cultures grown up in vitro, biotechnology began to be associated with genetic engineering, and at present these two concepts are even often used as synonyms. At present, there are known several dozens of definitions of biotechnology (see, e.g., Blinov 2003). There are also official international definitions, for example: 'Biotechnology represents a complex sphere of activity in which new methods of modern biotechnology are connected with the established practice of traditional biotechnical procedures. The basis of this growing knowledge-intensive industry is made by the complex of methods giving a chance to the person to change purposefully the structure of deoxyribonucleic acid (DNA), or genetic material, plants, animals and microorganisms as a result of receiving useful products and technologies' (the UN 1992: ch. 16). We understand *biotechnology as a set of scientific and industrial methods of production of various products through using live organisms and biological processes.*

The main directions of modern biotechnology are the biotechnology of food, agriculture, means and products for industrial and household use, pharmaceuticals and other medical preparations, environment protection against pollution, *etc*.

1. History of Biotechnology before the Start of the Cybernetic Revolution

In spite of the fact that biotechnology is a rather new branch, the period of 'traditional' microbiological production goes back to the Stone Age: yeast bread, yoghurt, beer, wine, vinegar are used since ancient times. The first scientific foundations of biotechnology were set by Louis Pasteur who discovered the fermentation nature. At the end of the 19th and the beginning of the 20th century the knowledge in microbiology which found increasing practical application was actively accumulated. In 1917, the Hungarian engineer Károly Ereky introduced the term 'biotechnology'.

Some scholars (Glick and Pasternak 2002) mark the following periods of development of biotechnology: 1) until 1917 it was the period of 'conventional' microbiological production; 2) from 1917 to 1973 – the period of invention of laying scientific foundations for modern biotechnology. In addition, this period is subdivided into two intervals: from 1917 to 1940 is in a way an 'incubatory' subperiod when biotechnologies were already actively used, but generally played no significant role in industry and economy; and from 1940 to 1970 when biotechnology already became a noticeable branch of industry; 3) from 1970 to the present is the period of the modern biotechnology, implementation of scientific research results in biotechnological production.

Such a periodization fits well our concept of the Cybernetic Revolution. Actually, starting from the 1940s and until the 1970s it is possible to speak about a rapid development of biotechnologies as a part of the scientific and information phase of the Cybernetic Revolution. They started to most powerfully develop from the 1970s on the basis of the Cybernetic Revolution.

Biotechnology appeared at the last stages of the industrial production principle alongside many other innovative branches. In the late 19th and early 20th centuries there appeared biofertilizers and biological preparations for pest control and combatting plant diseases, production experiments in bioconversion (Volova 1999). There was established the production of acetone, butanol, antibiotics, organic acids, vitamins, feed proteins, *etc.* with the help of microorganisms (Yegorova and Samuilova 1987).

The 1930–1940s were marked by the formation of a background for the transition to the Cybernetic Revolution. At that time there started industrial production of some vitamins, for example, vitamin C. The production of preparations by means of biotechnological methods increased. The first mass biotechnological production was the production of penicillin which started in 1943. The World War revealed an urgent necessity to organize mass production of cheap drugs, provision and vitamins.

2. The Initial Phase of the Cybernetic Revolution

2.1. Biotechnology becomes an essential branch of industry

According to our concept, the 1950s appear to be the beginning of the Cybernetic Revolution (of its scientific and information phase) when *a number of trends which used to be non-systemic in relation to the previous production principle obtained a systemic character*. During this period, biotechnology finally became a rapidly growing industrial sector which affects the whole economy. The biotechnological products were applied very widely. In the first decades after World War II there was organized large-scale production of amino acids, unicellular feed proteins (from oil and paper-pulp industry waste), steroids, and also cell culture of animals and plants was mastered. Already from the late 1940s there started organizing mass production of antibiotics. They found extensive use not only in medical industry, but also in agriculture for treatment of animals and plants, as bioadditives in fodders. Some highly effective forms of antibiotics were created with the help of mutations. The intact cells of microorganisms began to be widely used for receiving medical substances of the steroid type, large-scale production of vaccines was organized (Volova 1999). The production of pharmaceuticals became successful, and also a very profitable business; therefore, capitals and scientific forces flowed there. The quantity of medical supplies received via biotechnological method or the so-called 'red biotechnology' began to increase steadily. Let us emphasize that biotechnology became a powerful support for agriculture, as it provides the production of feed, additives, vitamins, and fertilizers, as well as the protection against pests. By means of biotechnology people also receive biofertilizers, amino acids, organic acids, alternative energy sources, and utilize biological waste. The industrial biotechnological production became possible also due to a wide implementation of automated processes. The automation, as noted above, is one of the main characteristics of the initial and middle phases of the Cybernetic Revolution.

2.2. Fundamental breakthroughs in biotechnologies

The breakthroughs in biotechnologies are connected, first of all, with the achievements in the study of the mechanism of transferring hereditary information. In 1953, James Watson and Francis Crick defined the structure of the DNA molecule. It laid the foundation for understanding the role of genetic information and basic opportunities of the purposeful transfer of genes from one organism to another. It opened enormous prospects, perhaps, surpassing the most courageous fantasies, like the ones presented by Herbert Wells in his novel 'The Island of Doctor Moreau'. The further discoveries connected with the genome were abundant. But, naturally, it took decades for the discoveries to their industrial implementation.

The 1970–1990s (the end of the initial and the transition to the middle phase of the Cybernetic revolution) were also marked by a tidal wave of advances in understanding of molecular biology.

We will enumerate some of them:

– 1973 – Herbert Boyer and Stanley Cohen laid the foundation of the recombinant DNA technology;

– 1975 – George Köhler and Cesar Milstein developed the technology of getting monoclonal antibodies;

– 1978 – the Genentech Company produced human insulin received by means of E. coli (colibacillus);

– 1981 – the first automatic synthesizers of DNA hit the market;

– 1982 – the first vaccine for animals received by the recombinant DNA technology is allowed for use in Europe;

– 1983 – hybrid Ti-plasmids are applied for the transformation of plants;

– 1988 – the method of the polymerase chain reaction (PCR) is invented.

As a result of the mentioned and not mentioned findings the genetic engineering becomes a powerful direction in biotechnology. The qualitatively new level of development of biotechnologies from the 1970s meant that within the frame of the Cybernetic revolution they already outgrew the potentialities founded yet by the industrial production principle and started developing on the new basis. During the last decades of the initial phase of the Cybernetic Revolution (the 1970s – the early 1990s) biotechnology became already quite a significant industrial branch which significantly contributes to agriculture (both plant growing, and cattle breeding, including also veterinary science), food and chemical industry, pharmaceuticals and medicine.

3. Biotechnology in the Modernization Phase of the Cybernetic Revolution

The 1990–2000s were marked by a powerful advance in biotechnology as a branch of industry.

Biotechnologies become a rapidly growing sector in which many countries started to invest significant amounts of money. The company Ernst&Young (EY) which over 30 years has been analyzing the biotechnological market recorded the sharp rise of the biotechnological industry in 2000. In the period from 2000 till 2005 the global revenue in the field of biotechnologies doubled and grew to US$ 50 billion. And in 2013 in the USA, Europe, Canada and Australia the revenue in the field of biotechnologies was about US$ 100 billion (Glen *et al.* 2013). From 2008 most investments in biotechnologies were made in R&D, *i.e.* innovations.

During this period the directions connected with genetic modification that developed in the previous phase became stronger. Organisms are cloned, a number of diseases are treated by means of genetic modifications. Along with production of medicine, bioadditives to feeding-stuffs, *etc*., the production of GMO became already a very significant segment of agriculture, the price increase for energy products led to a rapid growth of the production of biofuel (which includes GM foods).

No wonder that biotechnologies are considered as the most promising branch which can become the engine of a new innovative breakthrough.

The significance of biotechnologies is proved by a wide use of their achievements in different fields. Thus, in food industry there are practically no directions in which it could not be applied. Chemical production (in particular, polysaccharides, biodegradable polymers, biocatalysis, and also creation of new materials, for example, bioplastics), energetics, agriculture, municipal service (*e.g.*, in waste recycling), the branches connected with long storage of production; medicine and pharmacology; nanotechnologies; cosmetology; military branch are connected with biotechnology. At last, biotechnologies actively become common for people who use bioadditives and vitamins, special products in a diet, use certain type of cosmetic products, *etc*.

Biotechnologies contribute to the development of biosensors. A biosensor can be generally defined as a device that consists of a biological recognition system, often called a bioreceptor, and a transducer (Ferrari and Mauro 2006). Different biological materials such as enzymes, cells and antibodies are used in biosensors (Vo-Dinh *et al.* 2001), (Rusmini *et al.* 2007). Biosensors are able to transform biological energy into electric one. Thus, biosensor technology combines the achievements in biology and modern microelectronics. That is one of the most important ways to combine the technical and biological elements of the future self-regulating systems into a single system. There are different types of biosensors. Some of them are the devices which measure a limited number of the parameters (*e.g.*, blood glucose level), another measure a lot of parameters. At present they are used in many fields including for measuring the environmental pollutants. They are especially useful for different analyses in medicine, for example determination of metabolites or hormone levels (see also above about health monitoring in the future). Biosensors allow to control different changes in organism during surgery. An example of biosensors used at home is the glucometer, which helps to define the glucose concentration in blood. Biosensors are also used in measuring physical activity. For sportsmen biosensors are already the instruments of control of their physiological parameters. Hundreds and even thousands of biosensors combine the biochips. Biochip is a miniature device, essentially the entire laboratory which can perform thousands of simultaneous biochemical reactions. Biochips help to carry out quick analysis of a large number of biological parameters for different purposes, including diagnosis of a cancer, infections, and intoxications (Fung *et al.* 2001). Promising direction is the combination of biochips and nanorobots which, for example, can monitor the spread of viruses in the blood online (Cavalcanti *et al.* 2008).

The prospects of biotechnology are great. So far they are closely connected with microbiology, and microorganisms are present everywhere, even in this regard the sphere of application of biotechnologies will be boundless (from space needs to production and processing of mineral resources). At last, biotechnologies will become one of the main areas where the final phase of the Cybernetic revolution and the consecutive epochs (the 2030–2070s) will unfold.

4. The Characteristics of the Cybernetic Revolution in the Development and Application of Biotechnologies

The progress on the way to self-regulating systems. Already in the 1970s, computers were applied for the automation of biotechnological production. Computers rather quickly ceased to play a secondary role and have become the basis of automation (Zudin *et al.* 1987); one should point out that such journal as *Computers and Automation*, the editor of which was Edmund C. Berkeley, appeared not by chance in 1961. Dozens of devices for biotechnology were designed with the help of microprocessors, especially for work with DNA. In the modernization phase of the Cybernetic Revolution, the powerful development of ICT and software has raised the automation in biotechnological production and scientific researches to a new level.

In particular, in course of time factories producing biotechnological products demanded a lesser human participation. This substantially cheapens mass production of medicine and agricultural goods making them more available.

The software for the needs of genetic engineering is rapidly improving which appears to be the one of many examples of convergence of the directions of the Cybernetic Revolution. Today experts, without leaving the computer, select the necessary gene, model its embedding and behavior at transformation. The devices for automatic purification, cleaning of DNA and division into necessary fragments, transfer of a gene, *etc.* emerge. The sequenators (the devices for division of a chain of nucleic acids into nucleotides composing them) which used to occupy an impressive part of laboratories today are produced in the form of USB flash drivers and serve an example of miniaturization as well.[21]

It is extremely important that at present we can already speak about realization of the principles of self-regulation at the genome level. In particular,

[21] See about Oxford Nanopore Technologies. URL: https://www.nanoporetech.com/products-services/minion-mki

together with a useful gene, for example, of salt-tolerance in plants (Grinin *et al.* 2010), built in the special genes-controllers – the pro-motors which launch the necessary gene only under certain conditions (a high concentration of salt in the soil). Thus, there appears a self-regulating biological system (without human participation in the process, but controlled by people), which has not existed before and which, however, works in a proper way. In brief, we observe a prototype of autonomous and self-regulating biological systems which thanks to biotechnologies will be widely and actively used in the future in almost all spheres of life.

In biotechnologies self-regulation is widely applied also at the level of a cell. For example, the feedback strategies of a substratum and enzyme are used, known as the operon model for which in 1965 François Jacob and Jacques Monod got the Nobel Prize.

The achievements of contemporary genetic science and technology demonstrate the opportunities of creation of self-regulating biological (and ecological) systems of a rather high level in the future. Already today a genetic modification can change a whole population. Thus, the method of distributing genes via 'decoy' individuals is widely spread. For example, infertile mosquitoes had been massively introduced into the wild population, such ineffective crossing led to the reduction in a number of insects (Tkachuk 2011; Benedict and Robinson 2003).

Creation of new materials. In the 1940–1970s, one of the main directions was the development of industrial production of already known substances (*e.g.*, vitamins) or their analogues; however, during the same period there appeared the elements which did not exist in natural environment (*e.g.*, Humalog, which is a widely applied synthetic analogue of human insulin [Woollett 2012]). This sequence reminds the history of development of chemistry: at first people learned to produce the known substances, and then the artificial materials.

Due to biotechnologies many new materials are produced, for example, bioplastics. The main advantage of this material is that unlike ordinary plastic it can biodegrade. Thus, the main goal of bioplastics production is preserving environment, reducing the production of goods from non-renewable resources and cutting the discharging of carbon dioxide into the atmosphere. This is an important step to the creation of self-cleaning ecological systems in the future and also to the preservation of the environment. The range of bioplastic products is already very wide. From 2000 to 2008, the world consumption of compostable plastics made of starch, sugar and cellulose increased by 600 per cent (Ceresana Research 2011). However, the production of oil-free plastic amounts only one per cent so far. The experts consider that by 2020, the production of bioplastics will make 3.5–5 million tons, but, unfortunately, it will be only about 2 per cent of total production of plastics (Leshina 2012). Despite difficulties, biotechnology brings hope for more nonpolluting and renewable production which in the long-term perspective will allow saving resources.

Individualization in biotechnologies. Genetic engineering appears to be an especially bright example of individualization which is one of the main characteristics of the Cybernetic Revolution. Individualization in biotechnologies is connected, first of all, with the emerging opportunity to change the genome and to get new properties of an organism. According to this, in future the identity of each human body in the context of the formation of its life style, control over health, improvement of work of an organism, *etc.* will be taken into consideration. (Perhaps, individualization in biotechnologies will be applied not only to the human organism, but for example, to pets – dogs, cats, *etc.*).

Another example of individualization in biotechnology is cloning. Cloning by itself is a very widespread phenomenon in nature. One of the first experiments on cloning was performed by Georgy Lopashov in 1948. He proved that if the cell nucleus of other species is put into the ovule, the set of genes of an embryo will be the same as of an organism the cell nucleus of which is used. Numerous experiments showed that if the nucleus of adult cell is used, an embryo will be nonviable. The experiments on frogs proved that the cells which are not yet specialized can be used in cloning. Thus, the stem (immature) cells began to be used in cloning (Gurdon and Colman 1999). Since then the scientists have managed to clone pigs, sheep, cows, dogs and other animals. But these experiments were not so successful.

There is full and partial cloning of organisms. Of course, cloning of a whole organism is of greatest interest for public and also it provokes the largest disputes on the need and allowability of such kinds of researches. However, despite famous experiments, especially with the sheep Dolly, due to serious biological obstacles cloning will hardly develop much in the near future. It is necessary to point that the results of cloning are strongly exaggerated because of the aspiration for sensation. The sheep Dolly grew old twice quicker than the congeners. As a result, the animal was put down. Thousands of experiments were conducted with different animals, including more than a hundred anthropoids, but the positive result has not been achieved so far.

The therapeutic cloning provides much more ample opportunities for development and introduction at the level of commercial production. This type of cloning is described in more detail in the section about medicine.

Resource and energy saving is one of the main tasks and outcomes of introduction of biotechnology. The basic opportunities with respect to resources saving are connected with an opportunity to influence the genetic organization of living beings which at present serves the basis for the agricultural ('green') biotechnology which has already become a part of the initial phase of the Cybernetic Revolution. The breakthrough in this area is connected with *totipotency*, that is an ability of plants to form a full-fledged organism from a single cell. With the necessary gene transfer, one can make, for example, a variety of potato resistant to the Colorado beetle, or reduce the susceptibility to drought, cold and other stresses (Grinin *et al.* 2010). New agricultural technologies are of great importance for the developing countries. For example, genetically modified and pest resistant varieties of cotton plant and corn demand much smaller usage of insecticides which is more cost-effective and eco-friendly. The individualization is also noticeable in the animal genetic engineering which develops more slowly, but even now and in prospect it has an enormous value for agriculture and medicine (by means of genetic engineering it is possible to increase milk production, to improve quality of wool, *etc.*).

The increase and cheapening of food production is a global challenge for the humankind taking into account that the population number will continue to increase for several more decades (first of all in the poor and poorest countries, especially in Africa), perhaps, reaching nine or more billion people (see Population … 2012). Biotechnologies can make a huge contribution to the solution of the problem. Already today biotechnologies has made much with respect to the increase of the overall food production due to the increasing yield, resistance of plants to stresses, adaptation to local conditions through the creation of new and improvement of already existing genetically modified organisms (GMO), production of a significant amount of artificial nutrients, in particular, proteins.

The agricultural ('green') biotechnology which has already become the part of the initial phase of the Cybernetic Revolution is based on the technology of genetic modification (see, *e.g.*, Borlaug 2001).[22] GMOs allowed to significantly reduce the expenses, to increase crop capacity, to economize on the refusal from long selection. Due to genetic modification one can obtain the plants which are resistant to crop pests (*e.g.*, potatoes resistant to Colorado beetle), one can reduce susceptibility to drought, cold and other stress factors. One of the most widespread and widely discussed methods of genetic transformation is the transition of gene of resistance to chemical herbicide under the trade name Roundup (Williams *et al.* 2000; Richard *et al.* 2005). As a result when treated with Roundup, genetically modified plants remain intact but weeds are killed.

Despite various sanctions, the overall production of GMO is quickly growing in crop farming. Beginning from 2010, the GMO farming area in developing nations surpassed that in developed countries (Clive 2011). The analysis of the world economic effect of using biotechnological cultures shows the increase of profitability thanks to two sources. First, this is the reduction of production expenses (to 50 per cent) and the opportunity to get large crops on the same agricultural areas. Second, a considerable increase of harvest (in case of remov-

[22] About successes of Green Revolution in different countries see Wik *et al.* 2008; Pingali 2012.

al of restrictions on distribution of GMO World GDP could grow by US$ 200 billion [Kamionskaya 2011]).

The problems connected with GMO, real and imaginary, demand a special consideration. However, in comparison with the problem of hunger or malnutrition they seem less important. No doubt, that such production will increase (especially the production of biofuel) as it is the only way to solve food problems. The biotechnological production gives cheaper food-stuff, increases productivity in the places which used to be unsuitable for the cultivation of crops. New properties of farm animals and plants considerably save time and expenditures which are inevitable in case of long selection.

In general, as it was already told, achievements in genetic engineering will become one of the most breakthrough directions of the future revolution.

Biofuel. Biotechnology can help to produce rather cheap alternative energy sources. One can hardly say that biofuel is something new in the history of mankind as firewood, brushwood, *etc.* have been used from ancient times. But now it is extremely important to note that it is a renewable resource, whose overall production has become large notably thanks to biotechnologies. Now its global production amounts to more than 100 million tons (mainly, in the USA, Europe and Brazil). Today biofuel makes 10 per cent of all energy output; however, perhaps, its application will grow more than ten times by 2035. However, the majority (80 per cent) of biomass for biofuel is from forestry residues (Kopetz 2013). So the aspiration for maintenance of the ecological balance of the planet and to reduce wood use can strongly affect this source of alternative energy.

5. Forecasts of Development of Biotechnologies at the Final Phase of the Cybernetic Revolution

5.1. The introduction of new technologies in the modernization phase of production revolutions

The modernization phase of a production revolution is characterized by the two major tendencies: 1) the extensive distribution of new technologies with simultaneous improvements as a result; 2) the strengthening of social tensions and even struggle for necessary changes in some spheres of social life due to the introduction of these technologies. In order for the final phase of a production revolution to begin, the development of technologies during the modernization phase has to achieve both a rather large variety and 'density'. Taking into account that biotechnologies are innovative branches, any country which wants to be the leader in this field, will have to develop them anyway. On the one hand, we will observe a wide diffusion of biotechnologies into our lives: in nutrition, various nutritional supplements, influence on our body (through various branches of medicine, in particular cosmetic and one's own treatment of the body as, for example, body-builders do), *etc*. There must quickly develop both the branches which have already become a reality (*e.g*., the cultivation of genetically modified plants, affecting the productivity of domestic animals, production of biofuel), as well as the technologies which are less spread today, in particular in the development of biomaterials.

On the other hand, such a wide implementation of biotechnologies, undoubtedly, will intensify public, diplomatic and economic struggle against the change of traditions, national features, real or imaginary harm. Such a movement against cloning, GMO, computer selection, *etc.* has been already taking place in different countries. Such a reaction is quite natural, legitimate and in many respects useful though it may happen that conservatism will suppress progress. Just within the framework of this struggle and collisions, there may originate decisions which become important in the long term and will not only promote achieving of some balance, but also give an impetus to the development (let us remember that the ban on the importing of cotton fabrics in England served as a trigger for the development of its own cotton industry which became a cradle of the Industrial Revolution [Mantoux 1929; Allen 2009; Grinin and Korotayev 2015a]).

5.2. The beginning of the final phase of the Cybernetic Revolution and the development of the Scientific-Cybernetic production principle

Now, proceeding from current tendencies and a general sense of the development of the Cybernetic Revolution, it becomes possible to set out *the future developmental milestones in biotechnology* in the final phase of the Cybernetic Revolution (the 2030–2070s). As has already been mentioned, it can start in a rather narrow sphere, from which the innovations will start distributing and gradually penetrate the new areas.

Certainly, it is very difficult to anticipate the direction and moment of concrete discoveries. We suppose that at the very first stage biotechnology, as an independent direction, will play a less important role than medicine. It will be rather an important component of medical technologies, providing breakthroughs in the area of the treatment of diseases and the regulation or monitoring of organism functions.

Forecasts of self-regulation development. The level of controllability will increase considerably within a number of important systems connected with biotechnologies. Thus, probably, while transforming an organism, they will insert not a separate useful gene (Simon *et al.* 1983), but a whole set of necessary genes which will operate depending on environmental conditions. Such characteristics will be extremely important in the case of climate changes which are quite probable. It will become possible to choose the most optimal varieties of seeds and seedling for a unique combination of weather conditions and territory (the sort of imitation of evolutionary selection via automatic search in databases). Consequently, huge databases of such plant varieties and variations will be created. It is quite possible that in the future the whole process of getting a transgenic plant will take place without human participation, thus, it will become self-regulating.

It is possible to assume that by the end of the phase of self-regulating systems (and perhaps, even earlier, *e.g.*, by the 2050s) the agricultural biotechnologies will be already very developed. It may predict that the very adaptiveness of the modified products will allow for a response even to the smallest fluctuations of local conditions. In other words, it will be possible to order producers or collectors to create varieties of plants for individual greenhouses, hotbeds or plots. Farmers will be able to select individual fodder and drugs by means of programs and to order them via the Internet. Even an individual will be able to invent a houseplant hybrid suitable for the interior and to order its production and delivery. Thus, individualization will reach a new level.

The same refers to domestic animals: it will be possible to breed animals with peculiar characteristics within separate breeds of animals (or even by the individual order). It is probable that the selection of animals on the basis of genetic engineering will also develop in the direction of decreasing human participation.

The solution of urban and some environmental problems. Undoubtedly, there will occur important changes in using biotechnologies for the solution of environmental problems. Here it is possible to assume that biotechnologies will be intruded first of all in the urban ecology. It is necessary to consider that in the coming decades the urban population will increase by 40–50 per cent (see, *e.g*., NIC 2012). With the pace of development quickening in poor countries the problems of unsanitary conditions, incidences of disease, *etc*. will become very acute. And since different diseases can quickly spread worldwide, the problems of some countries will become problems for all countries. Among the problems which can be potentially solved by means of the development of biotechnologies, are those related to water cleaning, recycling of waste, liquidation of stray animals. Already today the micro-organisms for water cleaning are applied; with their help we also get bio-gas from waste recovery. But in the future these and similar problems will be solved by the development of self-regulating systems that will make it possible to solve a number of technical and scientific problems.

Thus, just as in the late 19th and early 20th centuries people coped with mass infections by means of biotechnologies, in the middle of the 21st century, the latest biotechnologies, perhaps, will help to solve the most vexing problems of cities where at least two thirds of the population will live. But the ecological problems, naturally, is not limited by the cities; it has to be extended to the cleaning of reservoirs and other ecosystems. The creation of ecological self-regulating systems will considerably reduce expenses and free huge territories occupied by waste deposits, as well as allow breeding fish in self-cleaning reservoirs.

One can assume that an important direction will be the creation of self-regulating ecological systems in resort and recreational territories which will provide the best conditions for rest and business.

The breakthrough in the sphere of resource saving. Biotechnology can help to solve many global issues, for example, to cheapen the production of medicines and foodstuffs including producing and making them in ecologically sound ways that can also keep or make the environment pristine, thereby considerably expanding their production. The solution to the food problem will come in the different ways, in particular due to the mass production of food protein whose shortage is sharply perceived in many societies (at present the feed protein for animals is generally produced in this way). Even now there are results based on the production of food proteins or, for example, imitation meat. But so far such a production is too expensive. Now a gram of laboratorial meat costs 1000 dollars (Zagorski 2012), but this is part of the usual process from the laboratory to mass cheap production.

The creation of new materials. The opportunities of creation of self-regulating and self-operating systems by means of biotechnologies, in particular genetic manipulations, opens an important direction in the field of new materials with desirable properties (*e.g.*, genetic material). At present genetic engineering is able to create not only the certain genes but also the entire genomes and even chromosomes. Artificial chromosomes can be added and consist of new genes which were not inserted into the organism (Dymond *et al.* 2011). It potentially allows for making substitutes for the natural process feedstock, for example, leather. The respective projects are already present now. For example, the Modern Meadow Company aims at making a revolution in the clothing industry by growing leather and other types of animal skin in the laboratories (Zagorski 2012).

The process of creation of biotechnological genuine leather will include several stages. At first scientists will select millions of cells from the donor animals. It can be both cattle and exotic animal species who are often killed only because of skin. Then these cells will be multiplied in bioreactors. At the following stage the cells will be mingled in one mass which will be formed in layers by means of the 3D bioprinter. The skin cells will create collagen fibers, and the 'meat' cells will form a real soft tissue. This process will take some weeks after which soft and fat tissues can be used in food production. Despite the exoticism and queerness of the above-described situation, in principle, it is very similar to the process of production of artificial furs which made it possible to solve the problem of warm clothes.

Section 4. NANOTECHNOLOGIES

1. Definition and History of Development of the Field

Definition and parameters. The humankind has been using nanomaterials for a long time whereas the ideas of nanotechnologies have appeared quite recently. Now with the existence of nanoparticles one can explain the peculiar properties of the well-known materials created in ancient times such as various enamels, painting materials, damask steel, *etc*.

Nanotechnologies is a widely used concept which can be conventionally defined as *an interdisciplinary area of fundamental and applied science, proving and developing practical methods of research*, *the analysis and synthesis*, *and also technology and methods of production of nanomaterials by a controlled manipulation of separate atoms and molecules*. The large scale of the concept of nanotechnologies makes it a problem not only to define them, but also to classify nanoproducts for whose specification there was even created a special group within European Commission.

Now in Technical Committee ISO/TC 229 the nanotechnologies are defined as follows (ISO 2005):

– knowledge and control of processes, as a rule, on a nanometer scale, but not excluding the scale of less than 100 nm in one or more measurements;

– use of properties of the objects and materials in the nanometer scale which differ from the properties of free atoms or molecules, for the creation of more perfect materials, devices, and systems realizing these properties.

Thus, the main point in nanotechnologies is using of the particles of no more than a certain size (to 100 nanometers in one measurement; one nanometer is equal to one milliard share of the meter, or 10^{-9} m).

Why nanoparticles became so popular? At this level the fundamental property of matter is clearly shown, that is realization of antipodal properties in its various systems. For example, at the macrolevel gold is a conductor, but at the nanolevel it is an insulator. The particles of some materials sizing from 1 to 100 nanometers show very good catalytical and adsorptive properties, other materials show wonderful optical properties. At the nanolevel the relation between the surface and volume changes, and thus, the properties of matter change. In the nature there exist nanosystems capable to be organized in special structures, gaining new properties, for example, the biopolymers (proteins, nucleic acids).

The peculiarity of nanoscience consists in the fact that it deals with atoms – compound particles of matter (a nanometer equals to a conditional construction of ten atoms of hydrogen built in a row). Now scientists already learned to operate with separate atoms and to merge them in blocks. In other words, in prospect, to receive a toothpick, it will be unnecessary to saw a tree, theoretically, it will be possible to force atoms to 'construct' it. Such an approach opens fantastic opportunities to create new materials with desirable properties. The prospect of this field was announced by the Nobel laureate Richard Feynman in the report 'There's Plenty of Room at the Bottom', presented in 1959 at the California Institute of Technology at the annual meeting of the American Physical Society. The scientist assumed that it would become possible to mechanically move single atoms by means of a manipulator of a corresponding size; at least, such a process would not contradict the known physical laws. Feynman offered a way of atom-by-atom assembly of objects that would allow reducing expenses on the material and saving energy in the production process. This direction was actively supported by scientific community and the era of discovery of nanocomposite materials began. At present, various and very ingenious means and forces are applied as such nuclear manipulators, but the solution of the problem is still far from done.

2. Nanotechnologies as an Outcome of the Cybernetic Revolution. Origin of Discipline and Field of Research

As it has been already mentioned, the first practical steps in the creation of nanotechnologies, as well as the ideological interpretation of this field were made in the 1950s (and the term, according to some scholars, was introduced in 1974 by the Japanese physicist Norio Taniguchi). In other words, nanotechnologies became a product of the Cybernetic Revolution. However, for quite a long time they stayed in the background of other important results. A rapid growth of practical interest in nanotechnologies began at the end of the initial phase of the Cybernetic Revolution, in the 1980s, with the publication of Eric Drexler's books 'Engines of Creation: The Coming Era of Nanotechnology' and 'Nano-Systems: Molecular Machinery, and Computation' (1987; see also Drexler 1992). But the term got the greatest expansion when it was caught-up by mass media. With the beginning of 'the nanotechnological race', the word 'nano' was especially frequently heard from TV screens and it flashed on newspaper pages. It meant that nanotechnologies started to be considered as a strategic branch of the future hegemony (together with others: biotechnologies, green power industry, *etc.*). Its ultimate task is to win the market of industrial production of new, important and highly sought technologies. The country which has won it can ensure economic growth and development for many years.

The race of nanotechnologies began at the suggestion of the USA which launched the competition. During President Clinton governance there started the development of the first program of National Science Foundation of the USA for studying the problems of nanotechnology. Explaining interest in the development of nanotechnologies, Clinton, in particular, declared, 'I earmark 500 million dollars in the current financial year (2001. – *A.G.*, *L.G.*), on the state nanotechnological initiative which will allow us to create new materials in the future (exceeding the existing ones a hundred times in characteristics), to write all the information of Congressional Library on the tiny device, to diagnose cancer diseases at the emergence of several diseased cells and to achieve other amazing results. The offered initiative is calculated, at least, in 20 years and promises to lead to important practical results' (see also Lane and Kalil 2007).

Almost at the same time at the request of the government a similar program was launched in Japan. A series of projects directed at the development of devices of nanometer size was planned, and the Angstrom Technology Project with the amount of financing in 185 million dollars became the most significant among them. It was calculated for 10 years, 80 firms participated in its realization. The Western European countries also joined the race and started carrying out the work in the area of nanotechnologies within the appropriate national programs. In Germany, nanotechnological researches are generally supported by the Ministry of Education, sciences, researches and technologies. In Great Britain the management of this direction is realized by Engineering and Physical Science Research Council, and also National Physical Laboratory. The first specialized journals *Nanotechnology* and *Nanobiology* appeared. In France the strategy of development of nanotechnologies is defined by the National Center of Scientific Researches. Russian Corporation of Nanotechnologies or Rusnano has been founded in Russia, nanoproduction of which in 2014 amounted to US$ 1 billion. There appeared the club of nanotechnologists which has united the scientists and industrialists of various branches. More and more attention to nanotechnologies is paid in China, South Korea, many other states, including Russia the starting positions of which are supposed to be rather good in this area (Dementiev 2008).

Now nanotechnology is one of the most intensively growing branches of economy.

3. The Development of Nanotechnologies in the Course of the Cybernetic Revolution

The characteristics and opportunities of nanotechnologies correlate with the concept of the Cybernetic Revolution, which is not surprising, as they originated from this revolution. They will play more and more important role in the process of its development. The stages of development of nanotechnologies even better fit the periodization of the Cybernetic Revolution, than biotechnologies and medicine.

1. The initial phase of the Cybernetic Revolution (the 1950s – the beginning of the 1990s) – the period of formation of the direction. Conditionally speaking, concerning nanotechnologies this is the period after 1959 when Richard Feynman presented the idea about constructing new materials from nanoparticles, before Bill Clinton's initiative in 2000. This period is characterized by

quite numerous scientific discoveries, many of them, however, did not get a significant application at that time yet.

For example, in 1956 D. N. Garkunov and I. V. Kragelsky described the effect of wearlessness. They found the phenomenon of spontaneous formation of a thin membrane of copper in pairs of friction between bronze and steel in aircraft parts. This membrane reduced deterioration and frictional force by ten times or more. The thickness of the membrane does not exceed 100 nanometers (the similar system is functioning in the joints). It is an example of the fact that the friction is represented not only as a destructive process, but under certain conditions it can be self-regulating, thus opening new and unknown properties. In 1968, Alfred Cho and John Arthur, the researchers from the Bell Company (USA), developed the theoretical bases of nanoprocessing of surfaces (see Rybalkina 2005: 21).

At this stage the development of nanotechnology in many respects was defined by the creation of devices of probe microscopy and devices with appropriate size. These devices are a sort of eyes and hands for the nanotechnologists. In particular, in 1981 the German physicists created a microscope which made it is possible to see separate atoms, and in 1985 the American physicists created the technology allowing precise measuring particles of a nanometer diameter.

The modernization phase (the period of distribution of innovations) of the Cybernetic Revolution is the period of the formation of 'modern nanotechnology' (the 1990–2020/30s). Nanotechnologies became an area of industrial production, the nanotechnological race between countries has started, dozens of projects and whole institutes of nanotechnologies have been created. The number of goods produced with nanotechnologies is rapidly increasing. The investments into researches increase, and the nanomaterials penetrate into various spheres: engineering, medicine, transport, aerospace and electronic industry, *etc*. According to the data of analytics of BBC Research (2012), the sales volume of products of nanotechnologies in 2009 amounted 11.67 billion dollars.

Euphoria from the opportunities provided by nanotechnologies. The analytics connect the first stage of the development of nanotechnologies (in 2000–2005) with the so-called 'passive nanostructures' (incremental nanotechnologies), but generally it was characterized by the production and use of nanodisperse powders. They were added in order to modify the properties of basic construction materials: metals and alloys, polymers, ceramics, and also in cosmetics, pharmaceuticals, *etc*. Now this is a rather primitive generation of nanomaterials already widely used in production, and they can be found in many goods. However, only few nanoprojects are applied in high-tech branches of industry.

The wide prospects due to the opportunities provided by nanotechnologies, stirred up by certain interests and mass media, caused euphoria of forecasts the majority of which had proven wrong or will hardly come true.[23] The emergence of such forecasts is quite natural. People want the process of creation of innovations and their implementation to go faster; at the same time they do not see the obstacles and challenges and do not take into account the economic crises which may change plans. Thus, the volume of nanoproduction is continuously growing despite the fact that the growth rates are not so fast as it has been predicted earlier.

A number of analysts suppose that after 2020 the era of 'radical nanosystems' in the form of nanorobots will start. At this stage there will be the development of nanobiotechnological and nanomedical systems which will significantly change human life, first of all increasing life expectancy. However, the theory of production revolutions argues that though there will appear a lot of innovations in the modernization phase, they will not be generally breakthrough – rather developing and improving, and many of them will be of low demand at all. At the same time the discoveries which will become the basis for the breakthrough are being prepared. But the breakthrough itself will happen later. In the field of nanotechnologies it will most likely happen in the 2030–2050s. Thus, the achievements of nanotechnologies which, according to a number of researchers, will happen by the 2020s (but, of course, not all of them) will actually take place one or two decades later. Nevertheless, in the coming decades the achievements which are already tested today in different areas, will be developed.

4. What Characteristics of the Cybernetic Revolution does the Development of Nanotechnologies Manifest?

The creation of new materials with desirable properties. One of the major problems facing the nanotechnology is how to make molecules to be grouped in a certain way, to self-organize in order to receive new materials or devices. The supramolecular branch of chemistry deals with this problem. It explores the interactions that can order molecules in a certain way, creating new substances and materials. There are different processes of self-assembling, for example, one of which is electrochemical anodic oxidation (anodizing) of aluminum, namely the one that leads to the formation of porous anodic oxidic membranes. At present in the field of nanocomposite constructional materials there appeared different technologies with various properties, for example protective, self-cleaning, antibacterial, *etc*.

The growth of systems' self-regulation properties. Self-organization of nanoparticles and self-organizing processes. A close connection between

[23] For example, according to the forecasts of the British Trade Department, by 2015, the demand for nanotechnologies would make not less than one trillion dollars a year, and the number of experts engaged in this branch would increase to two million people.

nanotechnologies and growing self-regulation within systems is based on the opportunity to make the processes of self-organization of matter to serve humans, forcing molecules and atoms to be ordered in a certain spatial and structural way. And creation of new materials with desirable properties is a direct way to make systems work in predetermined conditions. No wonder that nanotechnologies show striking examples of different self-regulating systems. One of such examples are self-cleaning nanocoatings. For example, self-cleaning of vessels from bacteria or the mechanism of self-cleaning of car glass nanopolish products. The nanopolishes modify the surface in such a way that a drop of water slides on it, collecting all the dirt whereas on a smooth surface, on the contrary, a water drop, while slipping, leaves dirt on the surface. It is called the 'lotus effect'. The idea is borrowed from nature: the leaves of lotus are covered with the smallest wax bulges and cavities, and thus, water flows down from them, completely washing away the dirt.

Miniaturization is the phenomenon which is characteristic of the modern technological progress. We can see that the majority of devices, gadgets, and professional tools become more convenient and of a more compact size. Miniaturization is most visible in nanotechnologies. Modern processors consist of more than a billion of transistors, but nanodevices will allow increasing this number by an order of magnitude. Now there is a race to reduce the manufacturing processes for semiconductors and chips to nanometers. Some companies have already passed to 45, 32, 28 nanometer process. The Intel Company uses 32 nanometer process for tablet computers and smartphones, and the Qualcomm Company uses 28 nanometer process for manufacturing chips. The Intel Company already starts mastering 14 nanometer process. In the last decade the process diminished in size approximately by three times (from 90 nanometers to 32 nanometers). In the near future they are eager to achieve the size of 7 or even 5 nanometers. Whether it will be successful and possible to achieve the invention of a principally new generation of computers due to such a decrease in size is not clear yet.

Nanotechnologies, energy efficiency and economy. Many nanotechnologies aim at energy saving, and also at the invention of alternative energy sources. So, the decreasing size of process technology not only increases operating speed of electronic devices and packing density on the chip, but also reduces their energy consumption. And, for example, 'smart glass' for rooms is capable to react to change in illumination and environmental temperature by corresponding change in transparency and heat conduction. There are many various projects of such saving. Thus, a wide use of electronic paper could reduce deforestation. Nanotechnology also can help to solve the problems of sewage treatment.[24]

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[24] The Chinese scientists created a system which can produce electricity by decomposition of organic substances, alongside removing organic compounds from waste water. Yanbiao Liu with

Nanotechnologies are already actively applied in agriculture, in particular, in the production of fodders which allows a considerable cutting their consumption and providing the best accessibility. In crop farming the use of nanopowders combined with antibacterial components provides increasing resistance to poor weather conditions and increases productivity of many food crops, for example potatoes, crops, vegetable and fruit and berry crops.

5. Forecasts

5.1. Nanotechnologies as a breakthrough component in the final phase of the Cybernetic Revolution (the 2030–2070s)

One can trace all the characteristics of the Cybernetic Revolution in the future development of nanotechnologies: bionanotechnology and nanomedicine will start a vigorous development, the invention of technologies of regulating systems (in which nanorobots independently or as a part of more complex technology will play an important role), the production of new materials, saving of materials and energy (*e.g.*, in house due to nanomaterial for window glass; developing of targeted drug delivery system to minimize portion of medicine directly to the damaged area or even to separate cells, *etc*.).

Connection with medicine: large opportunities. Despite serious progress of nanotechnologies in electronics and other branches, the real nanotechnological revolution will most likely happen at first in medicine that will give an additional impulse to the development in other areas. As a result, the breakthrough in the final phase of the Cybernetic Revolution will be provided by deep integration of medicine with biotechnologies and nanotechnologies which will bring the emergence of various technologies of self-regulating systems. We have already mentioned some directions of integration of these branches in the previous sections. In general the prospects of such an integration are already evident. So, according to some forecasts, nanobiostructures capable of transposing medical nanosensors, medicines and even reconstructing cells of an organism will be created in a decade or so and in 15 years they will become everyday practice. Of course, their active use in diagnostics and developing means to acquire immunity will become an important direction in nanotechnologies. We already have examples of this process now. At the Engelhardt Institute of Molecular Biology (part of the Russian Academy of Sciences) they applied nanotechnologies to create a biochip (biosensor) allowing quick diagnosing of a number of dangerous diseases, including tuberculosis. The development of nanotechnologies seems quite promising in respect of creation materials imitating properties of, for example, bone tissue. Nanotechnologies are already implemented in such surgeries as nano neuro knitting for repair of sev-

colleagues developed a photocatalytic fuel cell on the basis of nanotubes which uses solar energy to destroy organic compounds in waste water and converts chemical energy into the electric one.

ered optic tract, implantation of artificial limbs with high precision, cardiological surgery, *etc*.

The struggle with the cancer is one of the directions in which huge efforts of nanotechnology are concentrated is the struggle with cancer.

One can suppose that cancer treatment will become possible as soon as there is found a method to better target a certain layer of cells in a necessary part of the organism. However, it is possible that cancer will be defeated without destroying cancer cells, but by means of the method to fight metastases. The work is conducted in various directions here. Perhaps, the organism will give a clue. For example, it is known that metastases do not appear in heart tissues: obviously, there are some defense mechanisms which should be discovered (Marx 2013).

There are some examples of new directions of the cancer control based on nanotechnologies. For example, the system of carcinoma treatment is being developed based on heating of nanoparticles of iron oxide which are put into the infected tissue and influenced with a magnetic field as a result of which particles heat up and destroy cells.

At the Laboratory of Nanophotonics at Rice University in Houston, Professors Naomi Halas and Peter Nordlander, invented a new class of nanoparticles with unique optical properties – nanoshells. With a diameter 20 times smaller than red blood cells, they can freely move in the blood system. Special proteins, that is antibodies attacking cancer cells are specifically attached to the surface of cartridges. Some hours later after their injection the organism is beamed with infrared light which nanoshells transform into the thermal energy. This energy destroys cancer cells, and that the neighbouring healthy cells are almost not injured.

The important direction of research in the area of oncotherapy consists in automatic ‘smart’ hitting of the malignant cells by nanoparticles. The thing is that, only one-millionth part of the revolutionary new substance Herceptin, used to treat a considerable number of patients with breast cancer, would target the diseased cell. To make the transportation of Herceptin more effective, a group of American scientists invented a special model of a capsule from porous silicon into which the medicine is injected and is directly delivered just to the damaged cell. Now this technology is being clinically tested. The American scientist Mark Davis discovered a special capsule which has a structure similar to sugar and therefore, is not rejected and not excreted by the organism. A preparation is put into this capsule and can be stored in the organism for weeks. It is searching for a tumor moving within the blood-vascular system. Cancer cells are more acidic, than the usual, healthy cells, and, when finding such cells, the capsule opens and discharges the strong medicine. A patient with a pancreas terminal cancer, at the stage of metastasis was subjected to such cure and is still alive and even did not lose his hair after chemotherapy.

A future direction of medicine is the development of diagnostic methods that are also cost-cutting. We have already spoken about nanochips which can play an important role in medicine. The nanorobots which will be able not only to perform medical functions, but also to control individual cellular nourishing and excrete waste products will be put into practice. Nanorobots can be used for the solution of a wide range of problems, including diagnostics and the treatment of diseases, fighting ageing, reconstruction of some parts of human body, production of various heavy-duty constructions (Mallouk and Sen 2009).

It is clear that some promising technologies which are forecasted today, will fail to become successful in the future. But there is no doubt that the use of nanomaterials, nanorobots suitable for research, and other nanotechnologies will create important backgrounds for the future era of self-regulating systems in the area of medicine.

The connection with biotechnologies and agriculture. Other important directions are researches in the field of nanobiotechnologies. One can mention here the development of controlled protein synthesis technologies for receiving peptides with desirable immunogenic properties. Vector systems for the cloning of immunologically significant proteins of the causative agents of the diseases and vaccines of the new generation possessing a high activity and safety are created. Research is being conducted on creating nanoparticles for making genetically engineered proteins, the development of biochips and test systems for biological screening (Persidis 1998), immune monitoring and forecasting of dangerous and economically significant contagions of animals. Biochip technology is constantly improving and their manufacturing is cheapening (Rusmini *et al.* 2007).

It is expected that by means of nanotechnologies and use of robots the development and application of biotechnologies will significantly advance in the direction of creating self-regulating systems of farming, where agricultural operations will be for the most part performed in an autonomous mode. Many technologies will appear to promote this process. Thus, the implementation of membrane systems for cleaning, and also special biocidal coverings and silver-based materials will facilitate and increase the level of managing the farm livestock and providing them with high quality water. It is assumed that the use of nanotechnologies will allow changing technology of cultivation of lands due to the use of nanosensors, nanopesticides and a system for decentralized water purification. Nanotechnologies will make it possible to treat plants at the genetic level and allow creating high-yielding plant varieties especially resistant to the unfavorable conditions (Balabanov 2010). Today there are some innovative ideas which can be further elaborated in the agriculture. In particular, there appear microbial preparations based on associative, endophytic and symbiotic bacteria. These preparations are intended to produce and convey various enzymes and low-molecular biological active agents (nanoobjects) in plants. These can improve adaptation of plants to unfavorable environmental conditions: pollution by toxic metals, salinization, superacidity, *etc*. A fundamental approach to getting high quality seed material is essentially developed. This approach is as follows. Biologically active and phytosanitary components which can increase the adaptation of seeds and plants to real negative environmental conditions are constructed in the form of multifunctional nanochips.

Various prospects of using nanotechnologies in the Cybernetic Revolution and at the mature stages of Scientific-Cybernetic production principle. Nanotechnologies have considerable prospects. The components of nanoelectronics, photonics, neuroelectronic interfaces and nanoelectromechanical systems will be developed. Then on the basis of the achieved results it is expected to advance to a regulated self-assembly of nanosystems, the creation of three-dimensional networks, nanorobots *etc*. One can also speak about the use of molecular devices, nuclear design, *etc*. Especially alluring prospects are observed in the development of nanomechanics, nanomechanical engineering and nanorobotics.

Quite long ago there appeared an idea where data creation and storage is performed not by means of a special condition of the environment (*e.g.*, magnetic, electric, and optical), but through the use of nanotechnologies, for example, the replacement of silicon, the basic material in the production of semiconductor devices, by carbon nanotubes. In this case a bit of information can be stored in the form of numerous atoms, for example, of 100 atoms. It would reduce the sizes of processors by an order of magnitude or would essentially increase their operation speed. Now the number of transistors in the processor reached a billion and more. However, a few years ago the goal was set to create a processor with more than one trillion transistors by the 2010s (that would lead to radical increase of the ICT opportunities). Most likely, this is an unreal task to solve even by the 2020s, before the beginning of the final phase of the Cybernetic Revolution. It is supposed that this level will be achieved later, as we are already in the process of developing this phase (this would also open new horizons of full replacement of the information computer equipment due to a transition from using silicon to nanomaterials).

However, it is possible that the smallest computers will have an essentially new basis. According to Eric Drexler, nanomechanics and not nanoelectronics can become such a base. He has developed mechanical constructions for the main components of the nanocomputer – memory cells, logical bytes.

From special structures, such as fullerenes, nanotubes, nanocones and others, molecules can be gathered in the shape of various nanodetails – tooth wheels, rods, bearing details, rotors of molecular turbines, moving parts of manipulators, *etc*. The assembly of the finished parts into a mechanical design can be realized by using the assemblers (self-assemblers) with the biological macromolecules attached to the details capable of selective connection with each other. This idea was realized by Professor James Tour and his colleagues from Texas Rice University who in 2005 created a molecular mechanical design – the all-molecular four-wheel nanocar about 2 nanometers wide consuming light energy. It consisted of about 300 atoms and had a frame and axes. The development and creation of the nanocar took eight years. The scientists plan to create nanotransport devices, the nanotrucks, to transport molecules to conveyors in nanofactories (Balabanov 2010).

Certainly, this is more like toys, than research for practical use. They remind us of the steam toys like the mechanisms created by the Greek mechanic Heronus Alexandrinus, who amazed the audience in the 1st century AD. They hardly had any similarity with a steam-engine. But unlike Heronus who even did not think of a practical use of steam, the current nanotechnologists are absorbed with practical application. Therefore, the creation of nanomechanical engineering is quite real, though a long-term perspective. It will most likely happen close to the end of the current century. The same refers to nanorobotics. At the present, the expected designs of nanorobots and their use exist only in forecasts.

There is an opinion that in the 2030s some nanodevices will be implanted into human brain and will be able to perform the input and output of necessary signals from the brain cells and this can even make learning and getting education become unnecessary. But it causes great doubts. Even if such a cyborgization is realizable in principle, it will occur essentially later.

Anyway it is obvious that both nanomechanical engineering and nanorobotics will propel the development of self-regulating systems to a new level towards the formation of an industry that will design such systems (similar the use of engines promoted their industrial manufacturing – mechanical engineering).

Conclusion

The described processes must prove the idea that the final phase of the Cybernetic Revolution will be the era of a rapid development of self-regulating systems. Actually, already now we use some systems of the kind, but do not take them as such. Other self-regulating systems have not found a broad application yet, but soon enough they can become a part of our everyday practice. With the emergence of machines in the preceding centuries there appeared dozens of bright insights about their future application, and at the same time numerous ideas which failed to come true. And today it is difficult to define what will become a reality and what will not. But there is no doubt that the development proceeds towards the invention and wide distribution of self-regulating systems. We expect the development of such systems which will work almost independently and control important aspects of human life like today computer programs of spelling start checking your style or spelling. All this demands a deep understanding of the field of minimization as a solution to important present day and emerging problems. As already mentioned, the Cybernetic Revolution (like any production revolution) brings changes in all spheres of production and areas of life. However, these changes being part of a single large process will happen not simultaneously.

Now it makes sense to say a few words about changes in other spheres.

Demography. Each phase of production revolution is inevitably connected with demographic changes. In general the production revolution changes the type of demographic model of population reproduction. It is expressed in a radical increase of population number, its growth rates and changes of demographic structure of society. During the Agrarian Revolution the population and its density grew tenfold (from several to hundreds million people). In the course of the Industrial Revolution it became possible to reduce drastically mortality and to extend life expectancy. Population generally increased very significantly (*e.g.*, the population of Great Britain increased five times in the interval from the mid-18th to the mid-19th century). The structure of population was also changed: the urban population was increasing at the expense of the rural.

As a result, the global population of the Earth is increasing. This growth applied, first of all to the developing countries and actually continued the trends of demographic revolution of the industrial era. But on the other hand, demographic revolution was completed in the developed countries in the form of a so-called demographic transition which consisted in reducing fertility. At the same time life expectancy and its quality considerably increased. The demographic transition is actually the result of the initial phase of the Cybernetic revolution. Today fertility rates fall in the increasing number of developing countries. In the developed countries as well as in some developing countries one can observe the increase in the proportion of aged population.

Deduction. Hence one may say that the final phase of the Cybernetic Revolution will change the quality and life expectancy (see Figs. 4–5) and will change the law of population replacement. In some developed countries life expectancy can increase to 95–100 years and in other countries it will reach the level of today's the most successful countries (like Japan) – 80–84 years but possibly it will be even higher. The process of population ageing will be visible in most countries of the world (probably, except for African countries). At the same time fertility decline and the exhaust of demographic dividend in most countries of the third world will lead to the great changes of the demographic structure, for example there will be the strong decline in the proportion of children and young people and the number of aged people will increase. Of course, it is possible that the countries will try to solve the problem of shortage of children developing the methods of artificial growing of children out of maternal placenta. Successful attempts will affect the family institution which is already weak.

Power industry. During the previous production revolutions the energy source would also change. The Agrarian Revolution brought biological energy into use, that was strength of animals; the Industrial one used at first water power, then it was replaced by steam power and then electricity and fuels.

To start the Cybernetic Revolution there has already existed an adequate energy source, namely, electricity. The idea that a new leading energy source will become thermonuclear, hydrogen or some other new type of power, has not been realized yet. There is a question: whether an adequate energy source for the final phase of Cybernetic Revolution has to appear? The experience from previous revolutions shows that it is not necessary at all. The transition to the irrigational intensive agriculture did not demand the obligatory use of animal draught power (for plowing) as well as the first sectors of the machine industry quite managed with the known water energy source. However later, in the end of the final phase of every production revolution and during the transition to mature stages of every production principle, new sources of energy were already appearing (so, the completion of the Agrarian Revolution in the rain fed zones was connected with agriculture with the use of bulls and oxen; and the completion of the Industrial Revolution – with the use of steam energy). It should be noted that in both cases it was not totally unknown energy. Steam energy was occasionally used since the 17th century.

Deduction. Essentially new power source will not be required to start the final phase of the Cybernetic Revolution therefore the development of alternative (low carbon) power engineering will not play a decisive role here. However, a new energy source has to appear either during the final stage of revolution, or a bit later. Also, most likely, it will not be absolutely new and not previously used. Most probably, thanks to technical innovations, it will become possible 'to tame' and to make sufficiently available this or that type of alternative energy (hydrogen, thermonuclear, solar; or it will be the invention of easily stored electric power which will also solve the problem with a power source for eco-friendly transport). At the mature stages of production principle changes in the energy area are also taking place which create the base for the new production revolution (so during the period of maturity of the craft-agrarian production principle the power of water acquired those properties, used for driving mechanisms, and during the period of maturity of the trade-industrial production principle – the electric power became such a source). But what energy will appear at the final stage of the scientific-cybernetic production principle is difficult to imagine so far.

Communications. The production revolution surely changes the ways of communication. In the beginning of the Industrial Revolution there was invented a new type of information technology which created one of the impulsive forces of communication. We mean the invention of printing. The role of the new types of communication and connection (TV and computer) became even more essential at the beginning of the Cybernetic Revolution. Thus, the initial phases of the production revolution can be caused by the emergence of the new types of communication. However, it is not a prerequisite for the beginning of the final phase of production revolution (though writing appeared on the eve of the final phase of the Agrarian Revolution, its role was not essential). New forms of communication could appear at the end of the final phase of revolution or after it. For example, electric coupling (telegraph, telephone) was introduced after the termination of Industrial Revolution.

Deduction. In the next decades the emergence of essentially new types of communication is hardly possible. The development of communication has made great progress during the last decades and in general even surpassed the overall level of the development. Most likely, the revolutionary new types of mass communication can appear only toward the end of the 21st century. However the powerful progress in existing ICT as we mentioned above, is quite possible within the next three-four decades.

Transportation. It is not so easy to mark out any distinct regularities in transportation. At the beginning of the only one (Industrial) revolution the development of transport became one of its driving forces: the long-distance sailing ships played a crucial role in the organization of the oceanic trade. However, during the final phase or/and after it new forms of transportation appeared.

The final phase of the Agrarian Revolution (in its irrigation version form) was not substantially connected with large changes in transportation. However, the transition to the riding and development of sea communication occurred already during the final stage of the Agrarian revolution in its version with using plow and oxen or other draught form on the periphery and during the later period. At its initial phase the Industrial Revolution was connected with already tested oceanic water crafts capable of moving in any wind (not only the fair wind). Such crafts were widely developed during this revolution. Great Geographical discoveries without which the Industrial Revolution would have collapsed were also connected with this innovation. But the emergence of the steamship and further the engine happened already toward the end of the final phase of the Industrial Revolution. The emergence of a new means of transport gave it an unprecedented scope. New means of transport appeared much later (a car, a plane), and it was quite enough to start the Cybernetic Revolution. It, certainly, brought very fundamental changes to all means of transport, but created nothing essentially new so far (space transport is no object) though one may note the development of high-speed railways (but they play a secondary role).

Deduction. In the middle or the end of the final phase of the Cybernetic Revolution (approximately in the 2050–2060s) there can be expected the emergence of some new means of transport. An electric car with a large power capacity and speed could be a possible example. But taking into account 'the sense' of the Cybernetic Revolution (as the revolution of self-regulating systems) the breakthrough most likely will happen in the direction of self-driving vehicles and its control. That is the means of transport and systems will become self-regulating. Even today there exist some ideas concerning the realization of this opportunity and there are some projects (*e.g.*, Mercedes-Benz or Google) which they will try to realize in the nearest decades.

Specialist area. The production revolution radically changes the specialist area of people, their professional skills (competencies) and creates a need for new professionals. The farmer and the craftsman replaced the competences of the hunter and gatherer during the Agrarian Revolution. With the emergence of metals specialists, stone working disappeared. But nevertheless, during the era of the Agrarian Revolution, changes were happening rather slowly.

Almost the whole period of the industrial revolution, since the sixteenth century and, at least, till the last third of the nineteenth century, passed under the banner of battles pitting the skilled craftsmen against the Leviathan of technological progress. This period is full of episodes of prohibitions on inventions, the acceptance by the representatives of factories of various constraining laws, and a history of destroyers of machines, *etc*. Thus, the grounds for such bans and constraints were the most serious: product degeneration, falling of earnings, competition between the people who do not have the necessary professional skills. However, as a result, machinery replaced manual operation, waves of technological innovations wiped out the groups of experts. The initial phase (and even the middle one) of the Cybernetic Revolution, especially during the extensive use of computers, led, in a great number of cases, to the replacement of professional skills, including in the area of intellectual functioning: books proofreading, magazines and newspapers, translation from one language into another (though of poor quality but still helpful), collection of information, library and archiving, design, advertizing, photography, cinematography, *etc*. No wonder that the time when books in the standard form will be treated as a rarity is around the corner. The emergence of the opportunity 'to be your own' (the cameraman, the publisher, the artist, the photographer, bank and ticket cashier, *etc*.) became the sign of the times.

Deduction. Not least, further development will undermine the grounds of very many professions – from a doctor (as we mentioned above) and a teacher to the nurse and taxman and even pilots (the two last due to the creation of self-regulating cars and airplanes in the future).

As a whole the general course of development has to move towards the reduction of the number of people employed in the service sectors (both simple types and more difficult), but a lot of new professions will be required at the same time. Reduction of the people employed in the service sector happens at least in part as a result of development in the field of robotics. In fact, everybody will have his own electronic nurse (just like the children of ancient Greek prosperous citizens had teachers from among the slaves, and the children of nobility of landowners had the teacher from among the servants). By the way, it can be especially important for controlling children and nursing sick people who stay at home. If there emerge some relatively cheap multifunctional robots able to flexibly react to changes, then the life of people will become much more comfortable (but in that case their independence will decrease).

Robotics. The principles of functioning of robots and possibilities of their use support the idea of the development of self-regulating systems very well. Besides, only such devices could solve a problem of service of the increasingly numerous elderly generation and solve a problem of the lack of labor to some extent. Therefore, there is no doubt that this direction sooner or later is awaiting for bright future though now the volume of the world production of robots is very small – only some billion dollars. But its increase, most likely, will happen during the Cybernetic Revolution on the basis of creation of the future technologies. In 2007 Bill Gates argued that the robotics was in a similar state as Computers were in the 1970s when they with Paul Allen founded the Microsoft Company, supposing, apparently, that in the 2030s the robotics will become so important, as ICT today. However, it appears that robots will become very widespread some later, approximately in the 2050s. After all even according to the optimistic forecasts of Japanese association concerning robotics, by 2025 the turnover of the robotic branch will make only 50 billion dollars (Gates 2007), that is the volume absolutely insufficient for the takeover in the economy. The ideas about clever robots are valuable for us precisely because they clearly represent the most important characteristic of the Cybernetic Revolution – the increase of a number and variety of self-regulating systems. However, the forecasts concerning the forthcoming emergence of such robots will not come true (just as the predictions of the scholars such as Moravec failed).[25]

Some authors go further and consider that robots in the 21st century will have all characteristics of human mental and physical abilities. In their opinion, the 21st century will become a century of the post-biological world when as a result of the natural selection robots will force the person out of the pedestal of evolution and will develop under the influence of the new – post-biological evolution which can exceed the rates of the biological evolution millions of times (Wadhawan 2007).

[25] In the book *Mind Children: The Future of Robot and Human Intelligence* H. Moravec (1988), speaking about the influence of the Moore's law on the development of civilization, predicted the future of the robotics. He claimed that in the 2010 there will appear the models of robots, whose mental abilities will be identical to the brain of a lizard. They will be used for cleaning of rooms without intervention of people and some other purposes. Moravec claims that in another two decades models with mental capacities of a monkey will be created. Such robots will be able to define the elementary technical and domestic problems and objects and to solve them independently without instructions of the person.

Approaching of the robot mind to the human one would be, really, a significant step towards the creation of self-regulating systems of a new type. However, in our opinion, most likely, the process of creation of such robots will take essentially much time. Thus, like during any development, many (the majority) of the researches in the area of robotics does not give the expected results. According to the pen-picture of *The Wall Street Journal* journalist, the writer Lee Gutkind, who got inside of the top institute of invention of robots observed only the sad faces, damning the regular failed experiment instead of the triumph in the laboratories (Anders 2007).

Quite often during the period of rapid development the branch which seemed earlier to have no chances for success gets the first place. Most service robots are created for military. Some researchers, for example, suppose that one of the most perspective directions in the development of robots can become intimate services. In this sphere robots are already showing substantive results and prospects (Yeoman and Mars 2012).

But we believe that the development of robots (and not only surgical robots) in medical science will become a priority for the future. Linkage to medical science, as we already noted, can become the engine for the development of the branch.

Legal, ethical, pedagogical and ideological problems in the development of medicine. The faster the pace of scientific and technological progress, the more difficult it is for society to keep pace with those changes, the more flexible become morals, more sophisticated the right, different minorities are emerging, defending their, not always clear rights, the society becomes more tolerant. But at the same time traditions are subverted more easily and quicker and it becomes more difficult to distinguish good from bad (criteria for these concepts are disappearing), it is more difficult for parents to pass on their experience to children, *etc*. We have already discussed these changes (Grinin 2006b; Grinin and Korotayev 2009; Grinin L. E. and Grinin A. L. 2013). The well-known book by A. Toffler 'Future Shock' (Toffler 1970) did not lose its topicality at all (see also Fukuyama 2002). These problems surely demand much attention. In particular, it should be noted that very complicated ethical problems can appear and a potential risk of violation of the social and biological basis of human existence can emerge. It is difficult to imagine, what will be the outcome of all of these changes. Radical changes in the human body are able to affect seriously such basic things as understanding of the family, gender, already strong transformed, and to attitude to life. Just for this reason forecasting of the development of the Cybernetic Revolution is useful. It can help us become aware of the creation of the optimal social, legal and other instruments in advance, so that such changes would not take us completely unaware and so that it would be possible to minimize negative consequences. Eventually, the Cybernetic Revolution also will influence many social systems in order to make them more controllable by means new technologies. It means that there will be large or even radical changes in human behavior. Thus, now it is a high time to consider the positive and negative influence of the forthcoming transformations. Therefore, the technologies based on social insight and elimination of social problems have to be developed; importantly these technologies must be tested before the mass distribution of innovations leads to serious misgivings.

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