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Dual-Use Technologies in Production of XXI Soldier Combat Uniform and Civilian Goods

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Abstract—The necessity and possibility of using NBIC–technologies (nano-, bio-, info-, and cognitive technologies) in production of the uniform for the XXI soldier and application of these technologies in civilian areas (clothes, footwear, household textiles, medicine, sports, cosmetics etc.) are discussed. The outlines for implementation of such a project in the United States and a draft solution for a similar problem in the Russian Federation are described.

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INTRODUCTION

Development of the global textile production complies with the necessity of transition to the sixth technological mode based on nano-, bio-, info-, and cognitive technologies – NBIC-technologies [1]. There is a significant extension in the range of application of fibers and textile materials processed according to traditional technologies (mechanical treatment: spinning, weaving, braiding, and knitting; chemical treatment) in combination with NBIC-technologies [1, 2]. Economically advanced countries move textile production facilities into developing countries (China, India, Pakistan, Turkey etc.) and establish domestic production of technical and smart textile (technical, medical, sport, and cosmetic materials) with high added value. At present, the global production of technical textile has reached ~35% with an annual increase of ~10–12%, while the production of medical textile, which is conventionally referred to as technical, reaches 25% with an annual increase of up to 15%.

Dual-Use Technologies as Engine of Scientific and Technological Progress. Combat Uniform of XXI Soldier

All NBIC-technologies serve the military and defense sector, as well as a great number of absolutely civilian spheres of life (medicine, sports, recreation, fashion etc.), including production of a new generation of fibers, textiles, clothes, and other items on their basis.

Not to take advantage of the opportunity for dual use of the breakthrough technologies is to lose a possibility of their commercialization and compensation of expenses of the society on their military component. Products manufactured on the basis of the dual-use technologies have a high added value; it is profitable to make investments into such production and develop the economy. An example of creation of the combat uniform for the XXI soldier is a vivid illustration of the possibilities of NBIC-technologies in the defense and civilian industrial sectors and, in particular, in textile production.

During the recent decades there was a change in the strategy of the conduct of war and antiterrorist operations: to achieve the goal not at all costs but at minimal human losses among the country's soldiers and the civilian population from both sides. In the combat uniform of the modern soldier fire arms and military outfits are equal in significance.

In compliance with the modern requirements the combat army uniform has to be as light as possible (~20 kg) and multifunctional, simultaneously performing protective, communicative, sensory, and curative properties and intensifying the muscular and brain power of the soldier.

The requirements to the combat uniform of the modern soldier of the U.S., NATO, or Russian Army are as follows [3].

Comfort, which is achieved due to the uniform lightness, softness, and ease of use, as well as due to underwear climate control.

Multitasking functionality. The uniform has to ensure protection from hypothermia and hyperthermia, bacteriological and chemical attacks, radiation (X-ray and γ-radiation), and ballistic impact (bullets, explosive fragments, and shock waves). Also the uniform has to provide concealment (in the daytime and at night), superhydrophobic properties (water repellency), and fire protection.

Another necessary function of the soldier combat uniform is *communicativeness* (connection with the headquarters, companions, or field hospital). Instead of a radio set weighing several kilograms it is envisaged to apply a button radio (several grams) attached to the collar.

Other requirements include *sensority* (monitoring, warning, and response to external threats).

Another important component is *curative properties.* The combat uniform has to be able to provide first aid (transdermal injection of medicaments and fast putting of limbs in plaster or splint). Temperature and pressure sensors, a heart rate meter, and a blast protection device are installed.

The uniform is equipped with *independent power elements* (power generation, preservation, and utilization).

Orientation with respect to the terrain. The combat uniform has to be equipped with GPS, GLONASS, night lighting elements, diodes, and quantum dots.

The uniform should have a *long service life* and has to be *easy to decontaminate*. Economic requirements include *an affordable price, ease of maintenance and repair, and storage possibilities (for about 10 years)*.

It is evident that this set of multiple functions is not easy to achieve even for each individual component. Simultaneous achievement of all the above-listed properties is an even more complicated task, which is, however, theoretically possible to solve, which is proved by experience in development of such army uniforms in the United States, Great Britain, France, and South Korea. This range of requirements can vary towards a decrease in their number depending on the branch of the armed forces and the character of performed combat operations; however, the main requirements remain mandatory.

To achieve the above-listed requirements and provide the combat uniform with multitasking functionality it is necessary to solve a wide range of scientific and technological tasks with application of knowledge from various areas of fundamental natural sciences (physics, chemistry, and biology), as well as mathematics and special knowledge from applied sciences (micro- and nanoelectronics, bionics, materials science, medicine, textile chemistry, mechanical technology of textile production, technology of fibers and films manufacturing etc.). It is evident that well-coordinated teamwork of a team of specialists from all the above-listed fields of knowledge and practice will be necessary for implementation of such projects, both interdisciplinary and intersectoral.

A list of scientific and technological problems related to creation of the combat uniform of the XXI soldier is briefly outlined below; technical solutions for achievement of the uniform properties and functions indicated above are also given.

Lightness: nanofibers and nanofilms based on a new generation of fiber- and film-forming polymers are used in production of the uniform.

Underwear climate control: 3D structure of the fabric, which makes it possible to obtain breathable (membrane technology: nano- and micropores) and waterproof clothing.

Protection from hypothermia and hyperthermia: application of coatings from shape-memory polymers with reversible phase transitions.

Protection from bacteriological attacks: application of nanosized bactericide agents of a new generation.

Anti-ballistic protection: application of 3D textile materials from special synthetic fibers (aramid) and genetically modified spider silk (body armor, helmet, mask, and exoskeleton).

Superhydrophobic properties: lotus effect, i.e. creation of nanorough surface based on hydrophobic polymers (fluorinated ethylenes) on the surface of the fibers.

Protection from chemical attacks: introduction of molecular traps for toxic chemical agents (cyclodextrins and dendrimers) into the textile coating.

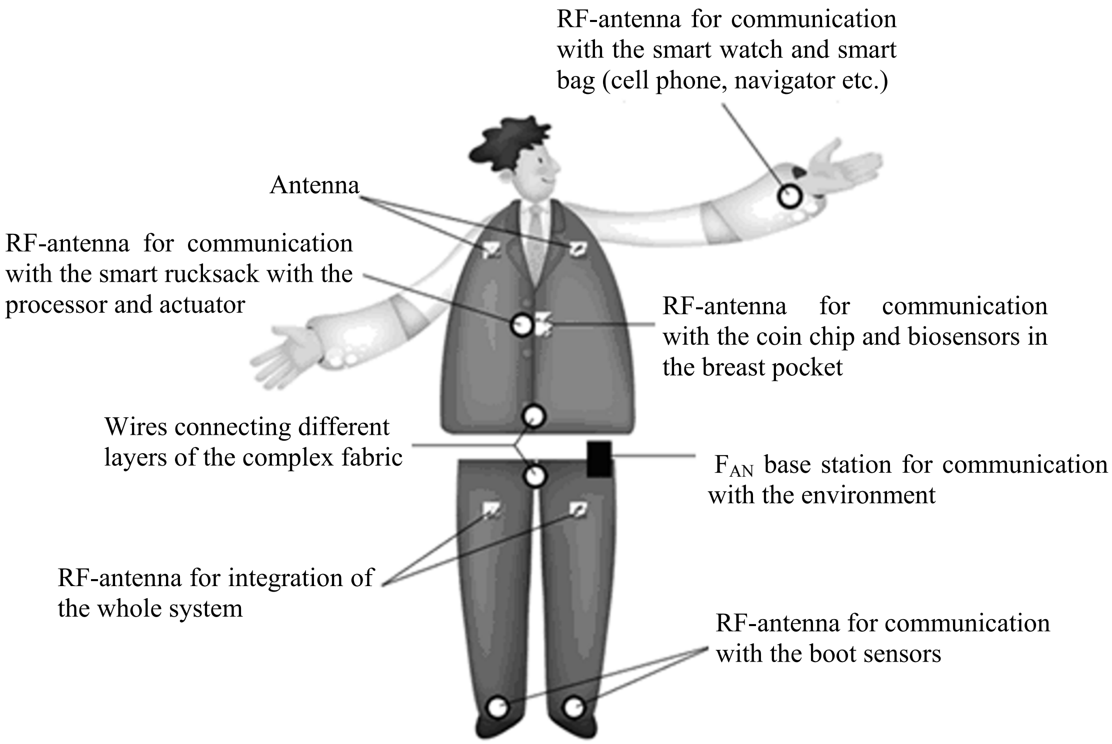

Fig. 1. Example of communicative clothing structure.

Radiation protection is the most complicated task. Provision of radiation protection is associated with significant weighting of the uniform. Partial protection against radioactive dust and weak X-ray and γ-radiation is possible.

Fire protection: application of fire-resistant fibers (aromatic polyamides) and antipyrens in nanoform.

Camouflage. Daytime: The ideal solution is the Delphian cloak on the basis of metamaterials with negative optics. Application of photo- and electrochromic dyes, reversibly changing the color in light or under the impact of a weak electric current. *Nighttime*: concealment from night vision devices. With respect to IR devices: selection of pattern and color; with regard to UV radars: there are works aimed at preventing radar detection, laboratory results are available.

Communicativeness: incorporation of nano- and microelectronic elements, quantum dots (creation of a flexible display on a textile basis), processor, antenna, GPS, GLONASS, and other micro- and nanogadgets into textile materials (clothing) (Fig. 1).

Sensority: application of polymer materials sensitive to physical, chemical, radiation, and bacteriological impacts; the materials transmit a signal to actuators for response and protection.

Curative properties: the uniform as first aid. Creation of a medication depot from textile materials. The uniform as a kind of transdermal dropper. Utilization of the textile as a reservoir for medicaments. Polymers with reversible phase transitions are used; they instantly form a plaster cast at the site of injury in response to a mechanical deformation (bullets and fragments).

Independent power supply: solar panels based on photoactive materials (silicon and photochromic dyes) and piezoelectricity (walking and other movements).

Orientation with regard to the terrain: GPS, GLONASS, and satellite communication. Incorporation of nanoelectronic devices (antennas, receivers, and flexible displays) into the uniform.

Intensification of muscular strength: application of the exoskeleton (Fig. 2) and mini-engines increasing the speed of movements, allowing super jumps and lifting of heavy loads. A biomimetic technique to apply mountain boots like a gecko lizard.

It should be emphasized that it is necessary to combine NBIC-technologies with traditional

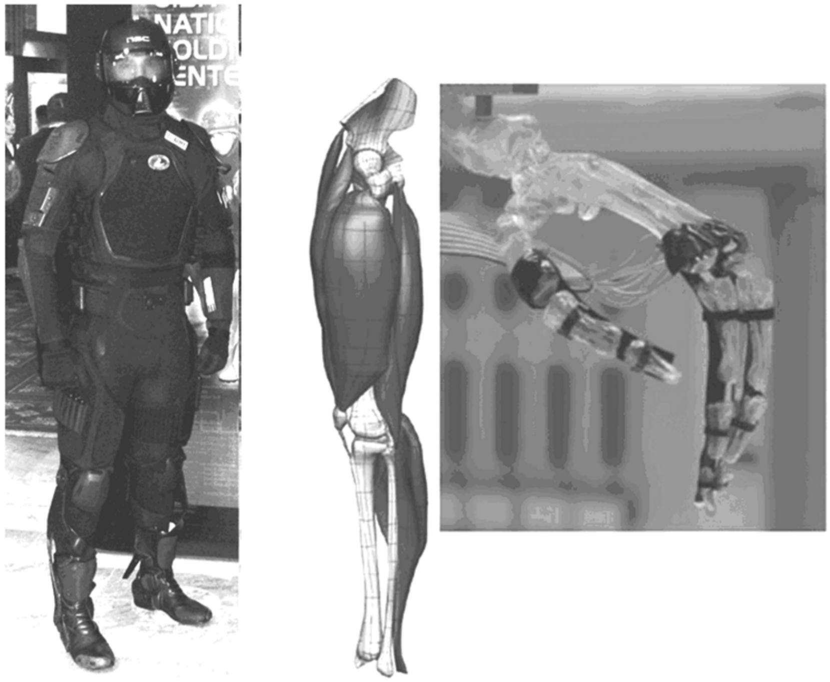

Fig. 2. Exoskeleton intensifying muscular strength several-fold.

technologies for manufacturing of textile materials and clothing such as the production of natural and chemical fibers (traditional methods and production from nanofibers), spinning, weaving, knitting, and chemical finishing technologies. Possibilities for creation of a multifunctional modern combat soldier uniform are illustrated by examples given in Table 1.

As can be seen from the presented examples, one and the same properties of clothing are most frequently achieved due to a combination of NBIC-technologies, and not due to one clothing production technology, which is a manifestation of synergism characteristic of these technologies and interdisciplinarity of each of them.

Below we will demonstrate a version of the cooperative effect of NBIC-technologies by an example of achieving lightness of the combat uniform (specified by the Pentagon within a range of 18–20 kg by 2020) possessing functional properties.

Light and strong nanofibers with targeted properties can be obtained only with the use of nanotechnologies,

Table 1. Examples of properties and functions of XXI soldier combat uniform achieved using NBIC-technologies

N	B	I	C
Lightness	Tactility	Independent power supply	Communicativeness
Tactility	Climate control	Sensority	Exoskeleton
Draping property	Bactericidal property	Communicativeness	Camouflage ability
Climate control	Hydrophobic property	Orientation on terrain	Sensority
Bactericidal property	Exoskeleton	Camouflage ability	
Antiballistic protection	Bio-detectors of threats	Exoskeleton	
Chemical protection	Antiballistic protection		
Camouflage ability	Camouflage ability		
Hydrophobic property			
Exoskeleton			

Table 2. Examples of achieving special properties and functions of civilian textile products manufactured based on NBIC-technologies

Medicine and cosmetics	Sports	Smart house	Engineering
Bactericidal property	Hydrophobic property (lotus effect)	Sensors warning about external and internal threats	Composites on the basis of nanofibers in rocket engineering, aircrafts, cars, motor boats, and yachts
Sensor diagnostics	Climate control of sportswear	Independent power supply, solar panels	Suits for astronauts and pilots of jet aircrafts
First aid provided by clothes	Protection from hypothermia and hyperthermia	Fire protection of household textile items	
Exoskeleton for disabled	Diagnostics during training sessions	Bactericidal properties of bed linen and bathroom items	
	Helmets for American football players, hockey players, and motorcyclists	Controllable color of curtains and wallpaper	

for example, on the basis of the electrospinning (electroforming) technology. It is a typical top-down technology (in the electric field there is splitting of the stream of the fiber-forming polymer melt, coming out of the nozzle, into nanostreams forming nanofibers) [1]. If genetically modified protein produced in the image and likeness of spider silk is used as a fiber-forming polymer, the resulting fiber is not only thin and light but it is also extra strong. In this case a technology simulating spider silk formation is reproduced. It is already bionics or biotechnology. Establishment of production of textile materials possessing curative properties from such fibers requires good knowledge of biology, wound healing mechanisms, and recent achievements in the field of efficient antimicrobial nanoagents. The technology for manufacturing of military clothing from light and strong fibers possessing curative properties (first aid), which has to be convenient, comfortable, and ergonomic, is based on implementation of patterns of visual, tactile, and emotional feelings of the individual. Communicativeness of such clothing is achieved mostly due to nanosized sensors, mini-antennas, transmitters, receivers, and other gadgets, organically built into the structure of fibers, filaments, or clothes. It is already micro-, nanoelectronics, and IT-technologies.

It is but one example of synergism, while it is possible to provide a great number of such examples illustrating interrelation of the bases of NBIC-technologies for creation of the uniform for the soldier of today and tomorrow.

As noted above, after some alterations achievements in the military and defense sector can successfully pass into civilian spheres. The same applies to the combat uniform production technology. The properties that have to be given to the army uniform are necessary, without exception, for textile products used in other spheres of life.

Examples given in Table 2 illustrate possibilities of NBIC-technologies in production of non-military textile articles (medicine, sport, modern household items, and equipment).

Table 3 provides expert assessment of the status of developments based on traditional technologies and dual-use NBIC-technologies aimed at the achievement of properties required for the army and civilian clothing in the Russian Federation and all over the world.

Options of XXI Soldier Combat Uniform Project

Scientific, technological, and engineering schools in many countries (United States, France, Germany, Japan, South Korea, Russia, China, and India) are working on the creation of the combat uniform for the XXI soldier.

The undisputed leader in the field of NBIC-technologies is the United States (more than half of all patents, developing and producing companies, greatest investments, greatest production volumes, most comprehensive content of the combat uniform ensured by NBIC-technologies, and testing of the uniform in different hot spots of the world).

Let us consider two organizational schemes of the U.S. scientific and technological projects on creation of the combat uniform for the soldier of XXI based on

Table 3. Level of developments (on global scale and in Russia) based on traditional technologies and NBIC-technologies used for provision of army and civilian clothing with multifunctional properties[a]

Clothing properties, functions	Globally	In Russia	Clothing properties, functions	Globally	In Russia
Comfort, lightness	+++	+	Hydrophobic properties	+++	++
Climate control	+++	–	Fire protection	+++	++
Protection from			Radiation protection	+	+
hypothermia	++	–	Communicativeness	+++	+
hyperthermia	++	–	Sensority	+++	–
Bactericidal property	+++	+	Curative properties	+++	+
Anti-ballistic protection	++	++	Independent power supply	++	–
Chemical protection	++	+	Orientation on terrain	+++	+
Camouflage ability	++	+	Muscular strength intensification	++	–

[a] (+++) advanced technology; (++) developed technology; (+) technology under development; (–) absence of development.

the requirements to the uniform and the engineering achievements aimed at implementing these requirements (Fig. 3).

Both schemes envisage mandatory project management, financing, and control from the Pentagon with active investment participation of all levels of the United States business and industry. The difference between the two schemes (developed especially to encourage competition) is that in scheme A all engineering developments are carried out in a specialized scientific and technological center (in Russian terms it is a specialized research and development institute on a complex, interdisciplinary, and intersectoral problem).

This center – Institute for Soldier Nanotechnologies (ISN) – is established within the framework of Massachusetts Institute of Technology (MIT), which is one of the leading world universities in the field of science

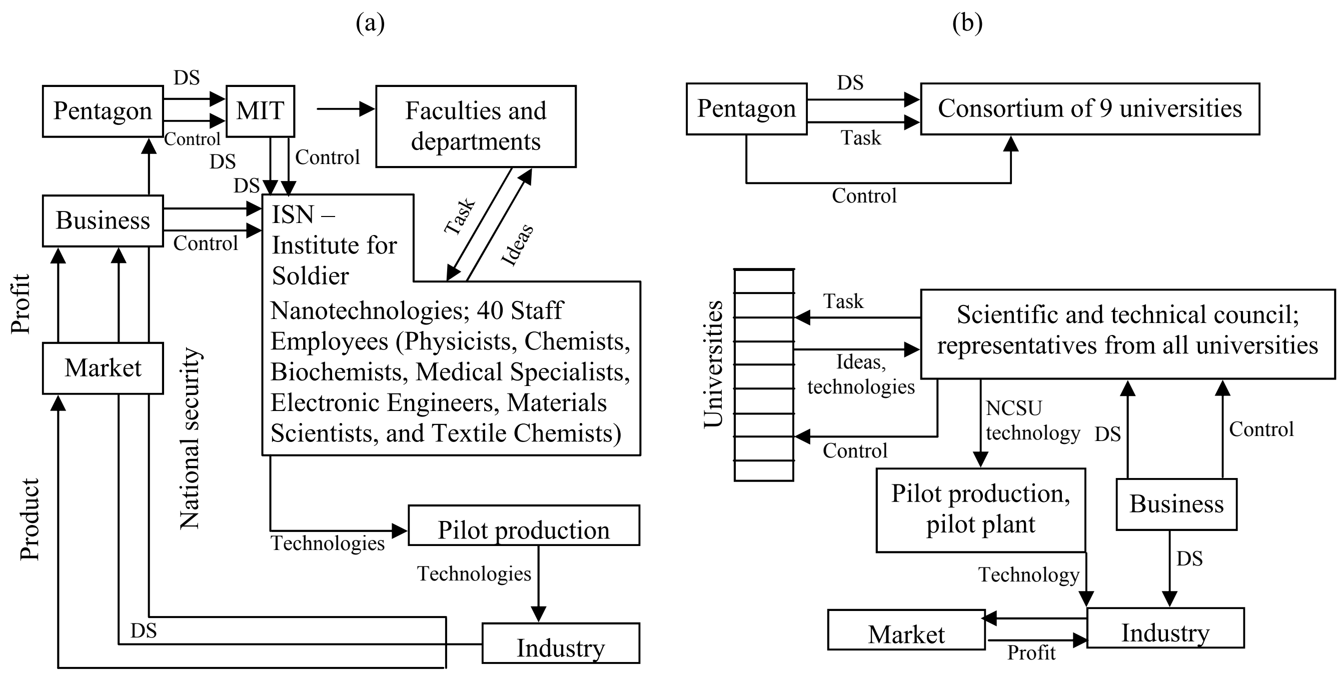

Fig. 3. Organizational schemes of U.S. projects on creation of XXI soldier uniform. (DS) is financing .

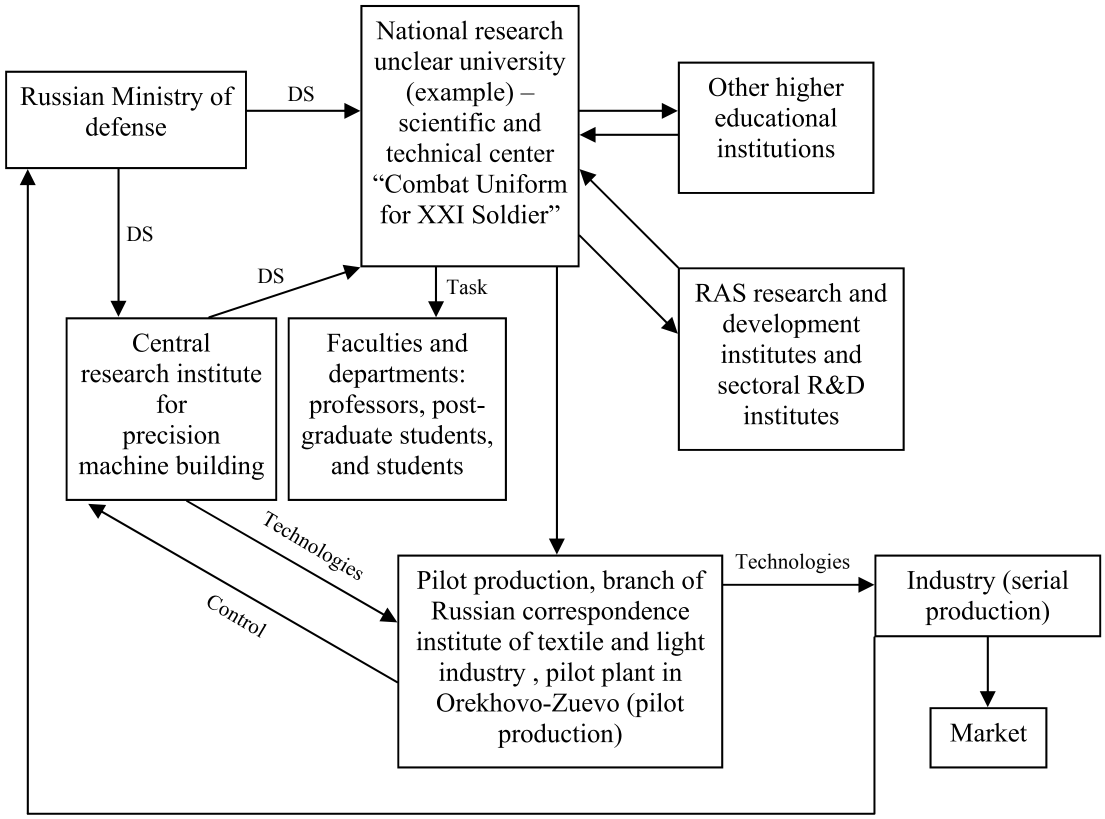

Fig. 4. Scheme of Russian project: combat uniform of XXI.

and technology. ISN employs a team of competent specialists of the highest qualification (physicists, chemists, medical scientists, biologists, mathematicians, biochemists, materials scientists, and textile technologists from different areas). The team is not numerous (~40 people). ISN can also involve in its work any person from MIT, from any faculty, any department, or other research institutions of MIT (more than 40 000 students and post-graduate students).

As noted above, the project is financed by the Pentagon (50 mln U.S. dollars for 5 years is not such an enormous amount as compared to the costs of Russian megaprojects Skolkovo, ROSNANO etc.). The business allocates nearly equal funds for development and implementation of the project. As a result, the Pentagon obtains the technology and the ordered products (buying it under contract from the industry), while the business and the industry obtain technologies for manufacturing of innovative products for civilian use with a significant added value (commercialization). Every party benefits from implementation of this scheme. The state solves the problem of national security. The business and the industry receive profits, which contributes to their further development. The scientific and engineering community obtains financial support for solution of complicated practical tasks, requiring a combination of fundamental research and engineering and technological solutions.

Higher educational institutions obtain a powerful impetus for training of specialists in new areas, which requires new and, first of all, interdisciplinary approaches to education.

As a taxpayer, the U.S. citizen gains confidence in cost-effectiveness of the project (transparency of the Congress reports) and a possibility to buy domestic innovative products on the domestic market. As a potential military servant or a person employed in a high-risk job, the U.S. citizen is provided with a new level of protection in case of an emergency situation.

The U.S. economy in general obtains a competitive advantage in selling new innovative army and civilian products on the domestic and international markets.

The second scheme of the project organization (Fig. 3b) with the same target function as in case of Fig. 3a differs from the latter by the fact that nine universities of a high scientific and technological level are involved into the solution of the problem of national importance and representatives from all nine universities form a scientific and technical council managing the project.

Options of the project on creation of the XXI soldier uniform successfully implemented in the United States are not only interesting in themselves but also as food for thought. According to the Pentagon reports, in 2009–2010 as a result of technologies implemented in the production of the combat uniform of the U.S. Army soldier the losses in the fighting strength of the U.S. Army were reduced by 15%, other things being equal.

The Russian military and industrial complex performs systematic research and development works on improvement of the combat uniform of the Russian Army soldier commissioned by the Ministry of Defense. A draft project of organization of a complex (institute or center) dealing with this problem is proposed (Fig. 4). The project takes into account both the global experience and the specific features of the domestic sectoral, university, and academic science, the state of the Russian economy and process industries.

This project is intersectoral and interdisciplinary. As neither higher educational institutions nor research and development institutes have specialists in all areas of this profile, implementation of the project has to be supervised by the leading institution in this field within the framework of the military and industrial complex (Central Research Institute for Precision Machine Building), possessing extensive experience in solution of problems related to development of the combat uniform for the Russian soldier [4]. Apart from that, it is necessary to establish a scientific, technological, and engineering center “Army Uniform for Russian Soldier of XXI” on the basis of one of the research and development institutes of the Russian Academy of Sciences or the national leading research university.

The center will be able to involve the best specialists from other institutions of higher education, academic, and sectoral research and development institutes on the principle of formation of temporary creative groups. Students, post-graduate students, and professors from different faculties and departments of higher educational institutions can take part in the work of the center.

The Ministry of Defense should be the project customer and investor, while the terms of reference for implementation of individual parts of the project and the project as a whole have to be specified by the leading sectoral institution (Central Research Institute for Precision Machine Building), which will perform integration, assembling of the project parts into a unified whole – the combat uniform for the Russian soldier of XXI.

CONCLUSIONS

The system lag of the Russian science in the sphere of NBIC-technologies, closing of many sectoral research and development institutes, weak financing of fundamental and practical works at the national level, and, above all, drastic deindustrialization of the process industries (machine-building, instrument-making, chemical, pharmaceutical, textile, light, and other industries) greatly impede competition in relation to this project. At the same time, the work on this interdisciplinary and intersectoral project will play the role of a locomotive for development of many Russian process industries and fundamental and applied sciences. It will also contribute to commercialization of these technologies, which would make a good addition to the budget of the Russian Federation.

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