Nuclear Energy and Solving Global Environmental Problems

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Abstract— **This paper shows how nuclear energetics is connected to global environmental problems, such as global climate change, depletion of natural resources, accumulation of industrial and consumption waste, air, water, and soil pollution, deforestation, desertification, and loss of biodiversity. The first six problems are closely intertwined with the planet's energy production. The use of fuels, especially of black coal, leads to a dramatic increase in air, water, and soil pollution levels, as well as to the accumulation of large waste amounts and catastrophic emissions of greenhouse gases. However, nuclear energetics allows harnessing energy without causing greenhouse gases and having the lowest carbon footprint all over its energy generation cycles. Nowadays, the impact of human activity on the biosphere has reached a global scale, changing the cycle of matter, the water balance of the planet, and radically affecting soils, vegetation, and fauna. Global environmental problems have become our reality. Anthropogenic activities have created new sources of pollution of the biosphere, which, ultimately, can create a threat to the existence of humanity itself. The comparison of the ecological effectiveness of various ways to generate energy shows that nuclear energy has an advantage over fuel energy sources with regards to all indicators and, along with water, wind and solar energy, forms the "green square" of the prospective energy development. Being natural-like as all the components of the "green square" nuclear energy is a direct embodiment of the sun's energy on earth.**

Keywords-energy; global environmental problems; climate change; depletion of resources; accumulation of waste; pollution; energy sources.

I. INTRODUCTION

The environmental threat to the existence of human civilization is officially recognized at the highest interstate level. Consumer attitude towards nature has put it on the brink of survival. The predominant patterns of production and consumption lead to environmental depletion increasing the risk to human life and health due to the reduced quality of the environment. Scientific and technological progresses have created a danger of an environmental catastrophe, and the very concept of development has been put into question.

Many scientific works have analyzed problems existing in modern global ecodynamics, including their connection to the growth of the planet's population, food and energy resources scarcity. The key features associated with the sustainable development of the nature-society system have been determined [1]–[3]. Researchers have come to the conclusion that global environmental problems and environmental safety are closely related to energy [4]–[9].

There is an urgent need to revise the scale of human values. For sustainable development, the energy issue needs to be dealt with.

The rest of the paper is structured as follows. Section III presents the state of the art. Section IV details our research and we conclude in Section V.

II. STATE OF THE ART

According to the report of the United Nations Committee on Environment and Development (UNEP – United Nations Environment Program), the prognosis for the development of humanity until 2032 is disappointing. Irreversible changes will occur under the influence of human activity on the planet. More than 70% of the earth's surface will be impacted one way or another, more than a quarter of all animal and plant species will be permanently lost; safe air, clean drinking water, undisturbed landscapes will be in deficit, and the ability of nature to recover from the human impact will diminish [10].

The high quality of the natural environment is a core value for humanity, an unconditional value category, and the essence of global environmental interests. According to the World Health Organization, 80% of all diseases are caused today by consumption of poor-quality drinking water [11]; according to the International Atomic Energy Agency (IAEA) estimates, five million people die from diseases associated with consumption of polluted and poor-quality water every year [12]. Water may become almost the main cause of future armed conflicts, same as oil today.

Statistical data on the ecological condition of Russia give disappointing forecasts. Today, more than a third of the urban population of Russia lives in areas where there is no atmospheric pollution monitoring, and more than half lives in cities with high and very high levels of atmospheric pollution [13].

Russia, along with the entire planet, has been experiencing serious environmental problems. The average air temperature has been growing, the permafrost has been receding, and various manifestations of climate instability have been observed.

V.I. Vernadsky saw the solution to environmental problems in changing worldview and ideological principles, i.e., in the noospheric thinking [14]. Therefore, the teaching of V.I. Vernadsky on the transition from the biosphere into the noosphere has recently become particularly relevant; it can serve as the basis for fundamental research on environmental problems and the practical search for their solution. The research on the patterns of biosphere development is key for rational environmental management.

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Noosphere is the area of interaction between society and nature; within its boundaries, the rational human activity becomes the determining factor of development. According to Vernadsky, the basic prerequisites for creating the noosphere are the following:

- unification of humanity
- transformation of the means of communication and information exchange
- discovery of new sources of energy
- social welfare
- equality between all people
- eradication of wars

Vernadsky concluded that humanity would turn into a new powerful geological force transforming the face of the planet with its thought and work in the course of its development.

Technical progress allows performing two main tasks:

- to improve the efficiency of the use of the planet's natural and resource potential;
- to exploit new forces of nature for the benefit of humanity.

The reference to "new sources of energy" and "new forces of nature" is a characteristic feature of Vernadsky's creative heritage.

Today, humanity has come close to the discovery and use of new physical phenomena, which is confirmed by the discovery of the Higgs boson, also referred to as the God particle, which opens the era of practical use of brilliant ideas that interconnect mass and energy. A kilo of matter can be converted into the amount of energy equal to a half of the annual Sayano-Shushenskaya hydroelectric power plant output. The Higgs boson is the golden key to the transformation of mass into energy; and this greatest discovery confirms the correctness of noospheric ideas and strengthens the faith in the power of intelligence.

The noospheric worldview, closely connected with the development of science and education, will develop together with further scientific discoveries. Noospheric thinking outlines ways to use and develop natural forces in the interests of humanity, productivity growth, rational environmental management, and the preservation and development of public health.

Scientific thought offers energetic and material capabilities that allow humanity not only to exploit the biosphere but also to reasonably transform the earth's biosphere itself in order to conserve and multiply all resources, as well as to make them renewable.

For years, we lived without resource shortages because we used to be a part of a self-consistent resource turnover, we were self-sufficient. Over the past 200 years, we have created the technosphere, in which we live. Before that, we were a part of nature, we used muscular strength of our own, of horses, mules, donkeys, and camels; we used the energy of wind and water. We were a part of nature without disturbing its "metabolism". Then, we came up with a steam engine, we invented electricity; as a result, we have built the technosphere, which is absolutely antagonistic to nature. This is a problem because this system is eliminating the resources and it is working against nature itself.

The solution to the problem is the creation of a nature-like technosphere, the use of nature-like technologies. It is necessary to create fundamentally new technologies that can be a part of the natural circulation. The Sun is a thermonuclear energy source and hundredths of a percent of the Sun's energy are converted through the mechanism of photosynthesis into energy, which provides nutriment to everything on Earth. This is a closed resource circulation.

Nature-like technologies and the achievements of scientific and technical progress will solve the problems of sustainable development.

III. RESEARCH

Global environmental problems are closely related to energy problems. If all countries of the world reach energy consumption levels of the United States of America or at least of "saving" Japan in the next 15 to 20 years, the total energy consumption will increase in accordance with the population almost 15 times [15]. The world electric power industry is not ready for such a "great leap". There is not enough organic fuel on the planet. Therefore, we can draw the following conclusion: energy development must explore the use of new powerful sources of energy and abandon burning fossil fuels.

The relationship between global environmental and energy problems is particularly apparent when comparing two indicators: the mass of resources required to produce a unit of energy and the global impact of greenhouse gas emissions on nature.

Figure 1 shows the main characteristics of various energy generation methods with two global indicators, namely greenhouse gas emissions and energy output per unit of weight of a substance. These indicate the efficiency of using the internal energy of substances, i.e., nuclear and thermonuclear energy. The existence of the solar system is based on these; the two reactors—a nuclear one inside the Earth and a thermonuclear one in the Sun—will remain main sources of energy. The proportion of energy harnessed from hydrocarbons will remain the largest. However, the limitedness of oil and gas reserves is obvious. The prospect for their active use is clear only for a few decades. During this time, oil and gas in the energy industry must be replaced by other sources. There are only two alternative options, namely the use of coal or nuclear energy. Modern technologies using both these types of raw materials will allow meeting the growing energy needs of humanity for the next few hundred years.

Nuclear is much more attractive compared to coal in terms of its impact on the environment. Humanity has already exceeded the limit of possible industrial development while maintaining the stability of biological systems and has reached the threshold of self-destruction of the biosphere. Environmental threats, such as the greenhouse effect and irreversible climate change, acid rains, reduction of biodiversity, increase of the content of toxic substances in the environment, require a new development strategy involving the coordinated functioning of the economy and ecosystem.

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WAY OF GENERATION		EMISSION OF GREENHOUSE GASES	AMOUNT OF ENERGY PER 1 KG OF SUBSTANCE
burning	coal (1 kg of coal > 567 g of ash)	CO_2 = 2.76 t (from burning of 1 t of coal)	7 kWh/kg
burning	natural gas	CO_2 = 1.62 t (form burning of 1 t of gas)	14 kWh/kg
nuclear energy		CO_2 = 0	24,000,000 kWh/kg
thermonuclear energy		CO_2 = 0	60,000,000 kWh/kg
quark-gluon level	Higgs boson	CO_2 = 0	6,940,387,213,578,000 kWh/kg

Figure 1. Global efficiency of different ways of energy generation [13]

In September 2017, at the International Ministerial Conference on Nuclear Power in the 21st century organized by the IAEA, Director General of the ROSATOM State Atomic Energy Corporation Alexey Likhachev emphasized the key role of the nuclear power industry in ensuring sustainable development and the global switch to low-carbon generation: “Everybody understands that the future belongs to green power. Sun, wind, water and atom, while supplementing and strengthening each other, must form the green square which will be the basis of the world carbonless mix…We are not competitors; all green energy sources are parts of the solution to the problem of the global climate change… The nuclear power industry meets all requirements set for the power of the future. This is a source of stable and environmentally friendly pure energy obtained at low cost. Nuclear power along with solar, wind and hydro energy make up the so-called “green square”, which will serve as a basis of the global power balance in the future...”[16].

The concept of “green square” implies that nuclear power is one of the key components of “green” energy. Together with solar, wind and hydropower, nuclear power forms the “green square” which will provide the basis for the world’s future zero-carbon balance and sustainable development.

In addition to the removal of a substance per se, the use of resources, as well as the generation of waste, should be taken into account. For example, a water nuclear power requires the use of water to cool condensates, as any other power plant which uses thermal turbines (coal, oil, gas) does. Other renewable energy sources have a number of advantages in this regard. Water sources where they already exist do not cause unnecessary difficulties, as the water used to cool the condensates is returned to nature.

In addition, nuclear energy is related to the formation of Radioactive Waste (RW). This issue requires special attention [13]. These are nuclear materials and radioactive substances, the further use of which is not envisaged. The problem of RW accumulation is primarily ecological. It is inextricably linked to the legacy accumulated during the period of the country's military arsenal build-up, but at the same time, the solution of the task of the final placement of RW is the key to the development of the nuclear industry in the future. The problem exists and needs to be addressed without shifting to subsequent generations.

Until recently, Russia adopted the practice of long-term storage of RW and delayed resolution of issues regarding their final isolation. That is why the solution of problems with regards to radiation heritage and ensuring the safety of the population and the environment is a serious technical, economic and, above all, environmental and social objective.

In 2015, the Russian Federation submitted the Fourth National Report on the Implementation of Obligations Arising from the Joint Convention, which confirmed that the basic principle of State policy of the Russian Federation in the field of RW is the transition to the practice of burying RW.

The Russian Federation Federal Law No. 190-FZ "On Radioactive Waste Management" initiated the establishment of the Unified State System for Radioactive Waste Management (USS RWM) (Figure 2).

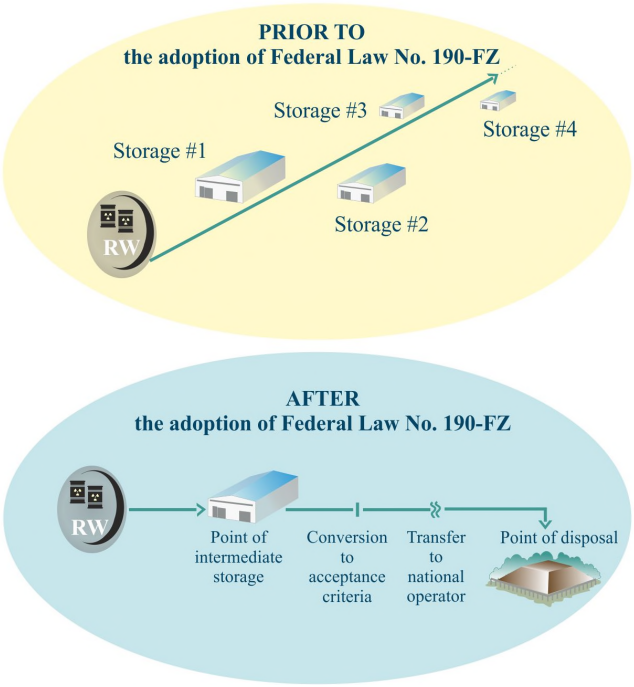

Figure. 2. Change of the system of handling the deleted RW after the adoption of Federal Law No. 190-FZ "On Radioactive Waste Management" [13]

The basic operating principles of USS RWM are:

- Priority to protect the life and health of present and future generations of people and the environment from the negative effects of RW;
- Prohibition of the import into and export from the Russian Federation of RW for the purpose of storage, processing and disposal, except in cases provided for in article 31 of Federal Law No. 190-FZ;
- Responsibility of organizations for ensuring safety in RW management up to their transfer to the national operator and for financial support of RW management works;

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- Accessibility to citizens and public associations of information related to safety and prevention of accidents regarding RW management, as well as other information on RW management.

The main purpose of the USS RWM is to organize and ensure safe and cost-effective management of RW, including its disposal. The Federal Law No. 190-FZ consistently reveals the composition, terms and stages of its establishment, and Government Decision No. 1185 of 19 November 2012 defines the procedure and terms for the establishment of the USS RWM. The formation of the USS RWM required profound changes at all stages of RW management (Figure 3) – starting with the technologies of RW management in organizations where RW is generated, and finishing with the formation of a national disposal operator and components of its structure.

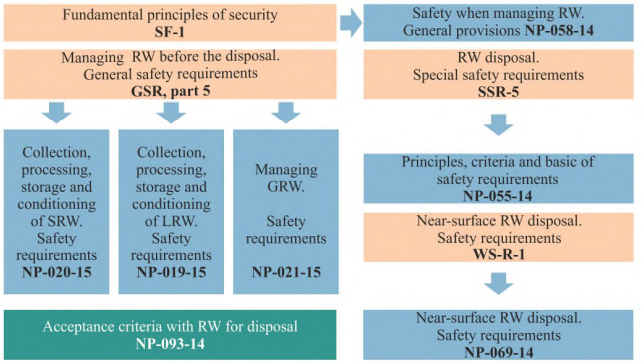

Figure. 3. Interrelation between IAEA safety requirements and Federal rules and standards which regulate safety during RW handling [13]

A fundamental solution to the issue is the transition to a closed nuclear fuel cycle [13]. The objectives of the transition to a closed nuclear fuel cycle are being formulated as follows. The first challenge is to fractionate high-level waste to escape disposal into deep geological formations to ensure safety and environmental acceptability. The second task is to develop industrial technologies of waste-free processing of Spent Nuclear Fuel (SNF), re-involvement of uranium, multiple recycling of plutonium, which is possible in a two-component system when by restoring the isotopic composition of plutonium developed in fast reactors, multiple recycling can be ensured. And the third, crucial task is international cooperation in accordance with the existing roles of countries in the two-component system, to comply with the nonproliferation regime.

Nowadays, it became obvious that the lifecycle of nuclear fuel does not end after it has worked the assigned term in the rector's core, and then was stored for the required time period in the spent fuel pool. Open nuclear fuel cycle provides for long-term storage of SNF and its further disposal. Closed cycle refers to reusage of nuclear fuel through the processing of SNF and manufacture of secondary fuel. Secondary fuel refers to fuel based on fissile material recovered from SNF. These are not only the residues of uranium-235 (regenerate, regenerated mixture REMIX) but also plutonium-239 accumulated in fuel tablets during the operation of nuclear fuel in the reactor.

It should be noted that countries supporting the concept of SNF reprocessing and recycling are now forming the main agenda for expanding nuclear energy in the world. Indeed, the development of technology and the public desire to support the development of nuclear energy is connected with the decision to process SNF.

Two-component energy refers to the synergistic existence of a reactor fleet on thermal and fast neutrons, which allow to increase the efficiency of using the potential of initial natural uranium by tens of times, due to the fact that in fast reactors the 238th isotope of uranium will be used almost in full. Of course, systems with 100% efficiency do not exist, but the use of natural uranium in a two-component system will increase the efficiency of natural uranium usage by 100-150 times. This is sufficient to meet humanity's need for electricity in the next millennium.

Closing the nuclear fuel cycle requires effective solutions to improve SNF processing technologies, fractionation, inclusion of minor actinides in the fuel and afterburning them (as a possible option) in fast neutron reactors.

Coexistence of reactors on thermal and fast neutrons will make it possible to reduce the cost of nuclear energy generation, in particular for the water-water energetic reactor technology, because it will be possible to abandon boron regulation, zirconium, which will exclude the possibility of zirconium-steam reactions, transition to other fuel element shells.

The schematic diagram of two-component nuclear power can be depicted with rather complex connections, but in reality, is quite simple and understandable at the intuition level. These are existing technologies with conversion, enrichment, fuel fabrication, energy generation, SNF reprocessing and recycling products back to thermal neutron reactors, as well as fuel fabrication for fast reactors, reprocessing their SNF, "leveling" the isotope composition of plutonium for its possible recycle.

When recycled in thermal neutron reactors, the isotopic composition of plutonium is deteriorated. With the initial content of about 1% plutonium in the SNF of these reactors, the 239th isotope in the mass fraction of its isotopes is in the range of 55-60%. As a result of the first recycle in thermal neutron reactors, the proportion of the 239th isotope of plutonium is reduced to 35-40% of the total volume of plutonium contained in the fuel composition. Only the addition of plutonium of fast reactors allows the recovery of isotopic composition and the provision of multiple recycling.

IV. CONCLUSION

This analysis has shown that global environmental problems, such as, first of all, global climate change,

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depletion of resources, waste accumulation, and pollution, are closely intertwined with how humanity harnesses energy.

According to the results of the comparison of various energy sources and from the point of view of influence on the abovementioned environmental problems, the best energy source is nuclear, which along with hydropower, solar and wind energy forms the "green square" of natural energy technologies.

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