Section One
INERT MATTER

Moon Exploration: the Evolution of Goals, Concepts, Projects, and Technologies from Observations to Total Colonization

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The paper considers the philosophical, historical, practical, and futurological aspects of the whole complex of relationships between human and humanity with the Moon from being an object of cognition, exploration, usage, and development to total colonization in the paradigm of the global future and expansion into outer space. A "comprehensive" definition of the concept of "Moon exploration" is given. The article provides periodization and a brief description of the history and prospects of the exploration of the Moon in the context of evolution of goals, concepts, projects, and technologies. The concept of total exploration and colonization of the Moon is developed, which includes: a general model of the exploration process; a general super global project covering many individual projects; environmentally friendly technologies and projects (their general classification and examples). The main conclusions are formulated.

Keywords: history, classification, concept, space, research, exploration and colonization of the Moon, project, humanity, evolution, environmentally friendly technology

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Introduction

Consider the philosophical, historical, practical and futurological aspects of the whole complex of our relationships with the Moon as an object of cognition, exploration, usage, and development of its natural resources up to the total, "absolute" colonization in the paradigm of the global future, the expansion of human and humanity into outer space [1].

Moon exploration is a goal-oriented process of human activity on an exploration of the Moon embracing study, research and usage of the Moon, all attributes of it, of its surface, subsoil, resources with the aim of survival and development of human and society on Earth and beyond Earth, on the Moon, reaching the point of total exploration and total colonization of the Moon, — after (Krichevsky & Bagrov, 2019: 37-38).

Let us give the most complete definition of the concept of "Moon exploration" in an interdisciplinary discourse.

Moon exploration is a comprehensive process of cognition, research, development, colonization, usage, application of the Moon by human and humanity in all forms and fields of activity, from individual to public consciousness, from the first observations to total mastery of the Moon as a physical object, its resources and space covering its relationships with Earth, Sun, and the entire Solar system, etc. [2]

In an extremely broad statement, "philosophy of the Moon," "philosophy of the relationships between human and humanity with the Moon", "philosophy of Moon exploration," and their various aspects are worthy of attention, purposeful research, reflection, inclusion in the scientific picture of the world, in the general culture of humanity, including those reflected in the "subculture of the Moon," which exists and develops in literature (especially in science fiction and poetry) and art.

Objectively, the Moon is an "eternal" witness, actor and object in the system of relationships between man and humanity with Earth and outer space as the closest extraterrestrial celestial body to Earth and the second most important actor influencing Earth (lunar phases, tides, eclipses, etc.) and all of us (the Sun is the first).

The exploration of the Moon in the "comprehensive" interpretation proposed above is an "eternal", super global complex problem for human civilization, for science, education and practice.

The Moon as a natural satellite of Earth has unique properties. Its research is complex and relevant, has a long history, theoretical and practical aspects.[3] The study of the process of the research and exploration of the Moon is necessary for analysis, forecasting, correction of space activities to the benefit of humanity on Earth and beyond it, for the transition to new technologies and expansion into space.

[1] The article is based on materials and research results of the author over the period of 2017-2020, including his 2 reports: 1) "Moon Exploration" at the Seminar of the SETI Scientific and Cultural Center at the State Astronomical Institute named after P. K. Sternberg of Moscow State University named after M. V. Lomonosov, Moscow, November 22, 2019; 2) "The evolution of concepts, programs, technologies for the research and exploration of the Moon" at the 26th International scientific annual conference at S. I. Vavilov Institute for the History of Science and Technology of the Russian Academy of Sciences, Moscow, April 2020. See also (Krichevsky, 2018; Krichevsky, 2019; Krichevsky & Bagrov, 2019).

[2] The author first gave this definition in a report on November 22, 2019, see in footnote 1.

[3] In the article, the author does not consider the genesis and evolution of the Moon as a celestial body, specific astronomical, physico-chemical and other characteristics. See (Galimov, 2010; The Moon, 2011; Travels to the Moon, 2019; Zeleny et al., 2012; Zeleny & Mitrofanov, 2015).

The evolution of ideas, concepts, programs, and technologies for the study and exploration of the Moon is reflected in natural philosophical texts, works on astronomy, in science fiction works, in publications, patents, projects in the theory and practice of space activities. Let us single out the works of Aristarchus of Samos, Galileo Galilei, Jules Verne, Konstantin Tsiolkovsky, Herbert Wells. There exist a lot of ideas, studies, projects, technologies, publications of supporters and participants in the process of research and exploration of the Moon throughout 20th–21st centuries, among them: Neil Armstrong, Vladimir Barmin, Wernher von Braun, Eric Galimov, Valentin Glushko, Sergey Korolev, Alexei Leonov, Ilon Mask, Eugene Cernan, Boris Chertok, Vladislav Shevchenko, Leo Zeleny, etc.[4]

In 2019-2020, the issue of research and exploration of the Moon became even more important in connection with the anniversary dates and new achievements in practical astronautics, in the domain of space activities: successful launch of the first lunar automatic interplanetary stations Moon-1, Moon-2, Moon-3 in 1959; the first landing of the Apollo-11 manned spacecraft and the first man's exit to the lunar surface in 1969; delivery of the automatic space rover Lunokhod-1 and its operation on the Moon in 1970, etc.[5] For more information, see Section 1, subsection "The second period."

In the 21st century, the problem of Moon research and exploration is considered to be bigger, more complex and more important than in the 20th century; it becomes one of the main directions of space activities and a priority in the process of space exploration, the next step and the leading edge in the process of expansion from Earth into outer space, exploration of the Solar system for the survival and development of man and humanity.[6]

Eric Galimov calls for introducing the Moon into the economy of humanity: "It is necessary to change traditional thinking, which regards the Moon as a distant astronomical object. The Moon should be included in the economical turnover of Earth. Moreover, this is not a dream; it is an inevitable and urgent economic task that must be solved until the end of this century" (Galimov, 2010: 268).

According to the academician of the Russian Academy of Sciences Boris Chertok, "modern technology is quite capable of colonizing the Moon. However, there are socio-political and international problems ... The Moon is a territory belonging to planet Earth ... it is a celestial body where people can live using local lunar resources. It is quite accessible to humanity and it will not require any new scientific discoveries." He also highlights the military aspect, which greatly complicates the process of the Moon exploration by humanity: "Lunar bases, unlike the ISS[7], can have a triple purpose: scientific, industrial-technological and military-strategic. It is possible to create a single Lunar Base for Earth only after overcoming the division of the world into military-political groups." (Cosmonautics of the 21st century, 2010: 27).

An academician of the Russian Academy of Sciences Lev Zeleny and Igor Mitrofanov emphasize an important role and potential of the Moon, call for a transition from research to exploration: "Is it possible to imagine the future development of terrestrial civilization without exploring and using the Moon? ... definitely not. The Earth-Moon system is a unique

[4] See (Cosmonautics of the 21st century, 2010; Galimov, 2010; The Moon , 2011; Merzhanov, 2018; Travels to the Moon, 2019; Tsiolkovsky, 1989; Website of NASA; Website of the Roscosmos; World Manned Cosmonautics, 2005; Zeleny et al., 2012; Zeleny & Mitrofanov, 2015).

[5] See (Krichevsky, 2019; The Moon, 2011; Travels to the Moon, 2019; Website of NASA; Website of the Roscosmos; World Manned Cosmonautics, 2005; Zeleny et al., 2012).

[6] See (Cosmonautics of the 21st century, 2010; Krichevsky, 2018-2020; Krichevsky & Bagrov, 2019).

[7] ISS — International Space Station.

astronomical object ... It is likely that the giant tides caused by the Moon, which was much closer to Earth 4 billion years ago, played an important role in the origin of earthly life. ... Space engineers consider our natural satellite as a future space continent of terrestrial civilization." They also believe that "the main direction for the coming decades is the exploration of the Moon through the integration of both manned and unmanned automatic means ... including those for working out the most important elements of Martian expeditions" (Zeleny & Mitrofanov, 2015: 66-67).

In the 21st century, humanity returns to the Moon: programs for sustainable exploration of the Moon, sustainable ways of living on the Moon, their scientific and practical aspects are discussed and created.[8] New programs and projects are implemented. Among them, the NASA's Artemis program takes the lead, and in 2024, 2 astronauts (a woman and a man) must land and start working on the Moon.[9]

The projects of lunar bases are being developed in the world, including the "Moon Village," etc., as prototypes of promising human settlements at a new stage of Moon exploration: "A human return to the Moon is now imminent following recent changes in NASA's future exploration directions. Other nations may well follow and, like the International Space Station (ISS), this approach could involve collective national initiatives. European Space Agency (ESA) Director General, Jan Woerner, is among those enthusiastic over the 'Moon Village' idea, which would have nations clustering together in adjoining domes located at the lunar south pole" (Spall, 2018).

The situation is interesting, complex and contradictory. The Moon is an ideal object for exploring "from scratch": almost untouched surface and environment, without a biosphere, territorial political and economic borders. However, humanity has not yet agreed on how to explore the Moon, and the process of its development is already underway.

Successful and effective Moon exploration requires new "rules of the game," a common strategy and a general super global project, significant funds and new technologies, the unification and distribution of efforts of the world community, the cooperation of space and other states, in balance with the solution of pressing problems on Earth.[10]

1. Periodization of the process of research and exploration of the Moon

The first period — before the beginning of the Space Age (until the end of the 1950s)

It is characterized by visual and instrumental observations of the Moon from Earth (from its surface, then from aircraft in the atmosphere), the emergence of ideas, concepts, hypotheses, theories, calculations, measurements, and estimates related to the origin, evolution and properties of the Moon.

Targeted exploration of the Moon began more than 2,200 years ago based on visual observations and mathematical calculations. It is a matter of common knowledge that in the 3rd century BC, Aristarchus of Samos determined the distance to the Moon and its diameter. In 1610, Galileo Galilei was the first person to look at the Moon through his telescope and to

[8] See (Meet the ESA experts, 2020; Olszewski & Locke, 2020; Spall, 2018; The Scientific Context, 2007).

[9] See (The Artemis Accords; Website of NASA).

[10] See (Krichevsky, 2019).

discover mountains and craters on it.[11] Then, the detailed maps of the surface of the visible side of the Moon were compiled, which were based on photographs since the middle of the 19th century.[12]

The second period — the Space Age (since 1959)

In addition to exploring the Moon from Earth, the use of unmanned and manned spacecraft, and the flights of people around the Moon and onto the Moon began.

In 2019, there were a number of important dates: 60th anniversary of the first flights of automatic stations to the Moon — Moon-1 flew ~ 6,000 km from the Moon, Moon-2 reached its surface, Moon-3 took and transferred the first photographs of the far side of the Moon (1959, USSR); 50th anniversary of the first landing of people on the Moon and the first human step on it (astronaut Neil Armstrong, 1969, Apollo-11, USA).

The period of the 1960s–1970s was marked by the "moon race" with the participation of the USSR and the USA competing for priority in the exploration of the Moon and delivery of the first human and the national flag onto it. The USA won it by successfully implementing the Apollo program. The USSR worked on and developed lunar programs, projects, and technologies: 1) flights of people around the Moon and to the Moon (astronaut Alexei Leonov was preparing to fly, and he could become the first person on the Moon); 2) delivery of lunar soil; 3) lunar rover Lunokhod; 4) creation of lunar bases, settlements ("Barmingrad" and others). Nevertheless, only points 2) and 3) were implemented. Moreover, it was 50 years ago: Moon-16 (soil delivery to Earth) and Lunokhod-1 (1970). The last person on the Moon was US astronaut Eugene Cernan (1934–2017). He left the Moon on December 14, 1972, and since then, it has been waiting for new people for almost 48 years.[13]

At the end of the 2010s, in the third period of the Space Age, a new second world "moon race" began with the participation of the USA, EU, China, Russia, India, Israel, Japan and other countries. Its supertask is the "second coming" of human to the Moon, the creation of permanent infrastructure, scientific bases, settlements, industry, space economy in addition to the earthly, extraction and use of resources, as well as colonization of the Moon in the paradigm of space exploration, creation of cosmic humanity.[14]

There are other approaches to the periodization of the process of Moon exploration and to estimating the beginning of the second lunar race, etc.

Lev Zeleny and Igor Mitrofanov believe that "the second period of lunar space exploration began in the 90s of the last century and has continued until the present ... Lunar projects of the leading space agencies that began in the first decade of this century, almost all are aimed at the transition from the research tasks to exploration" (Zeleny & Mitrofanov, 2015: 67, 70).

A number of independent experts in the field of space activities, for example, Andrei Ionin and Ivan Moiseev (Russia), believe that objectively there has been no second lunar race yet, but there is a PR campaign, and it tends to be wishful thinking under the absence of real economic opportunities, programs and technologies for large-scale and energetic exploration of the Moon, especially with the participation of people.[15]

[11] See (Berri, 1946: 44–45, 136–137), cited after (Krichevsky, 2019: 19).

[12] See (Krichevsky, 2019; Travels to the Moon, 2019).

[13] See (Krichevsky, 2019; Krichevsky, Bagrov, 2019; The Moon, 2011; Merzhanov, 2018; Website of NASA; Website of the Roscosmos; World Manned Cosmonautics, 2005; Zeleny et al., 2012).

[14] See (Krichevsky, 2018, 2019, 2020; Krichevsky & Bagrov 2019; Mayboroda, 2019; Medvedev, 2019).

[15] See (Medvedev, 2019).

2. General classification of goals, concepts, programs, technologies and the process of their evolution

Let us present a general classification of goals, concepts, programs, and technologies for the study and exploration of the Moon (based on the formalization of "target functions") and the process of their evolution in the form of three interconnected and "incremental" stages (first + second+ third):

First stage. Observation and description of the Moon for cognition, the use of its properties on Earth.

Second stage. Purposeful, systematic research of the Moon to create its adequate, complete model as a celestial body, including the genesis and evolution of the Moon, communications, interactions with Earth, the Sun, using the space technique and technologies in the 20th century, including contact research, for the development of science and education, as well as practical activity on Earth and in outer space.

Third stage. Development and use of natural resources, the features of the Moon for terrestrial civilization, including the colonization of the Moon, and for further expansion into outer space.

Moreover, the evolutionary process goes from individual private research to integrated long-term national and international projects and programs.

First stage — beginning of >3000 BC. Observations of the Moon, its phases, etc., creation of astronomical methods, technologies, and techniques for Moon exploration, calculations, knowledge accumulation.

This was the period of creating foundations and options for concepts, programs, projects, gaining experience in solving practical problems: calendars, eclipses, tides, etc.

Second stage is purposeful creation of descriptions, maps, globes, and other models of the Moon. Since the 1620s — observations through telescopes, discoveries, descriptions of structures and phenomena on the Moon; since the middle of the 19th century — photographing in combination with other technologies, research techniques, recording and filing; the 20th century was completed with radio communications, radar, computing and space technology, and the Internet.

Due to the rapidly growing flow of information, the process of accumulation, systematization of knowledge about the Moon, creation of new concepts, projects, and technologies accelerated. The period of 1960s–1970s was extremely important: photographing of the far side of the Moon became possible, and remote methods and technologies were supplemented with contact research of the Moon using space technology, especially during the flights of people to the Moon. The third stage began, but the process was stopped, "frozen" and "hung up" on the development of concepts, programs, projects, technologies for the period of approximately 40 years, during which the goals and objectives of the second stage were realized.

Third stage — since the 2020s. Moon exploration, its colonization (in perspective). New concepts, programs, projects and technologies, and corresponding new "rules of the game" are needed.

In connection with this, the author developed a new concept, investigated environmentally friendly technologies and projects, see Section 3. Main legal aspects of Moon exploration are highlighted and briefly reviewed: 1) human rights; 2) licensing; 3) intellectual property protection; 4) natural resources extraction and usage; 5) environmental protection; 6) new

technologies and technical activities regulation and safety; 7) natural and cultural heritage preservation (together with Alexander Bagrov (June 30, 1945 — August 20, 2020)).[16]

The world is creating new "rules of the game," programs, projects for Moon exploration, usage of its resources and space in the context of national and international law, important political, legal, technological initiatives and innovations are appearing. This can lead to a significant change in international space law and accelerate the process of Moon exploration.[17]

More and more attention in outer space research and exploration is paid to the transition to space mining — the extraction of extraterrestrial resources, especially on the Moon.[18] According to Tatyana Ursul and Arkady Ursul, "... the first space deposit, most likely, will be the Moon, on which water will become the primarily produced resource used for the livelihood of people and as fuel for rocket and spacecraft. The need to use lunar natural resources to create lunar bases and to build space infrastructure there for the purpose of further space exploration testifies in favor of the speedy exploration of the Moon." They also draw attention to the fact that "having created an industrial and energy base in outer space (primarily on the Moon), it will be possible to transfer both energy-intensive and environmentally harmful production from Earth" (Ursul & Ursul, 2020: 19-20).

However, this is hardly possible with existing technologies, primarily because of the low efficiency of space transport: the cargo flow between the Earth and the Moon is limited, which will not allow solving the problems of transferring industrial production from Earth to the Moon until the transport problem is solved. In addition, space mining may impose restrictions on the extraction and use of natural resources, industrial production on the Moon owing also to the properties and characteristics of its environment. "For instance, condition of total processing, utilization of associated waste must become an absolute restriction on mining of mineral resources. On the Moon, natural conditions and mechanisms of degradation of human waste are principally different in comparison with those on Earth. Thrown away broken mechanism will lie on the Moon for millions of years in the same state. ... On the Earth we have already faced ecological consequences of waste piling with which natural recreational mechanisms do not cope. And on the Moon, where there are no such mechanisms at all, the problem of waste utilization must be solved with the first steps of its development. The problem of human waste utilization is partly solved on inhabited space stations; this experience must be used on the Moon, too. Different kinds of mineral waste can be used for lunar construction works. This implies simple and clear rule: you can mine as many resources as you can utilize waste from mining" (Krichevsky & Bagrov, 2019: 43).

The opportunities and prospects of creating permanent lunar bases and settlements of people on the Moon, the upcoming long and constant life of people and new risks raise a set of questions, new ideas, projects and technologies for ensuring safe and decent living conditions for people throughout the entire life cycle of a "cosmic" human beyond Earth, in communities on the Moon: from reproduction, conception, birth, further development, actualization, and up to death. This requires extensive scientific research and implementation of extremely complex, dangerous, and expensive practical activities of people in space, taking into account the risks and limitations of the process of Moon exploration, its conditions, properties, and characteristics of the lunar and near-Moon environment.[19] It includes the effects of new

[16] See (Krichevsky, 2019; Krichevsky & Bagrov, 2019).

[17] See (Executive Order, 2020; Krichevsky & Bagrov, 2019).

[18] See (Executive Order, 2020; Ursul & Ursul, 2020; Krichevsky & Bagrov, 2019).

[19] See (Cosmonautics of the 21st century, 2010; Galimov, 2010; Krichevsky, 2020; The Moon, 2011; Mayboroda, 2019; Medvedev, 2019).

hazardous factors, physical and chemical, electromagnetic and other phenomena and effects (for example, lunar dust plasma can adversely affect both the work of space technology and human health, i.e. moon dust is a significant risk factor[20]).

3. The concept of the total exploration and colonization of the Moon

The author has developed the concept of total exploration and colonization of the Moon, which includes a general model of the process of Moon exploration, a superglobal project, and environmentally friendly technologies.[21]

In essence, this concept is simultaneously philosophical, practical, and futurological, synthesizing in the ultimate formulation of basic ideas, concepts, projects, and technologies aimed at total, "absolute" exploration of the Moon as a celestial body, its space and natural resources.

Hypothetically, in the future, the Moon can be used by humanity completely, up to its radical transformation and processing, for example, to restore and protect Earth or to ensure the existence or protection of extraterrestrial cosmic humanity, including with the aim to create a structure like a Dyson sphere, etc. However, at the same time, dangerous, irreversible consequences for the environment will arise, so the question of the possibility and admissibility of such transformations remains open.

3.1. General model of the process of Moon exploration

In addition to the existing models of the Moon as an object of research and exploration, a "General model of the process of Moon exploration" is required, which must cover the main scenarios, priorities, prospects, etc.

In contrast to the well-known strategies, concepts, research projects and industrial exploration of the Moon in the resource paradigm for supplying Earth, as well as providing fuel and other resources for the process of expansion into deep space, to Mars, etc.[22], the author proposes a "comprehensive" approach and a superglobal project for total exploration and colonization of the Moon by humanity (see also subsection 3.2).

Scenarios. There are two main scenarios of Moon exploration:

First scenario. Balanced, "deductive". Development and adoption of general "rules of the game," permissions and restrictions on the exploration of the Moon, its surface, subsoil, and resources taking into account priorities, zoning, stages, environmental and other aspects, creation of common institutions under the auspices of the UN, joint activities on the Moon under the control of international institutions , while minimizing contradictions and conflicts.

Second scenario. Extreme, "inductive". Slowing down and / or ignoring the general "rules of the game", chaotic exploration of the Moon, its territory and resources in the traditional way of exercising the "first-to-file" and "first-to-use" rights — by analogy with the experience of expansion on Earth, such as the "gold rush." "Moon rush," aimed at allocation, capture and monopolistic predatory use of the most valuable sites and resources will give rise to many contradictions and acute conflicts, including military ones.

The second scenario is more likely, which in fact was already proclaimed by the United States in 2020, implemented in the paradigm of their leadership and the formation of new

[20] See (Zeleny & Mitrofanov, 2015: 69-70).

[21] See (Krichevsky, 2018, 2019).

[22] See (Galimov, 2010; The Moon, 2011; Zeleny et al., 2012; Zeleny & Mitrofanov, 2015).

"rules of the game" and cooperation in the exploration of the natural resources of outer space and the Moon. This leads to the transformation of international space law, which is excessively conservative and has long hindered the process of space exploration and development of its resources. However, there is a risk of an imbalance of relationships due to the formation of new rules that do not take into account a number of important aspects and interests of all participants.[23]

There are various implementation options for each scenario. We will conditionally single out the minimum, optimal, and maximum options that can be worked out, taking into account the priorities, risks, restrictions, and other aspects of Moon exploration.

Priorities for Moon exploration must be formed and adjusted on the basis of value approach, taking into account zoning of its territory, stages, risks, restrictions, economic and technological capabilities, and prospects, etc.

Zoning of the territory for effective Moon exploration is necessary in order to: 1) accommodate scientific, industrial, residential, and transport infrastructure, as well as a system of protection against asteroid-comet hazard; 2) extraction of minerals; 3) protection and restoration of the environment; 4) search for and preservation of objects and items of natural and cultural heritage (these include unique natural objects — landscapes, rocks, craters, mountain peaks, caves, meteorites, etc.; the first technical objects on the Moon and traces of its exploration).

In Russia and the world, zoning of the Moon's territory is being carried out on the basis of mapping, surface and subsurface sounding, prospecting, mineral resource assessments, including distribution of water, metals, etc. There were preliminarily determined the best places for permanent lunar bases, human settlements in the area of the South Pole, taking into account a complex of factors (landscape, topography, lighting, direct visibility from Earth, presence of water and other minerals, etc.); important sites in the areas of the poles and the far side of the Moon, etc.[24] "The projects of the first stage should provide the solution of two practical problems for the preparation of the future exploration of the Moon: to select the most favorable region in the vicinity of the South Pole for the location of the Lunar test site with the subsequent construction of the attended lunar base on it and conducting of detailed physical and chemical studies of the polar regolith" (Zeleny & Mitrofanov, 2015: 71). Moreover, it will primarily be the research with the help of automatic spacecraft followed by manned flights and the activities of people on the Moon in the places attended by people, and then in permanent lunar bases and settlements.

The prospects for Moon exploration we will present as an optimistic forecast of three stages:

First stage. Creation of scientific, industrial, inhabited infrastructure, permanent scientific bases, industrial facilities, human settlements, space economy on the Moon, information, energy, transport communications in the Earth + Moon system, using new technologies (robots, 3D printing, etc.), as well as the space reserves, archives, etc. to preserve the earthly and lunar natural and cultural heritage of humanity throughout the 21st - 22nd centuries.

It includes the creation of "cosmic" human and "reserve" humanity [25] on the Moon for the survival of a human species of Homo sapiens and restoration of humanity in the event of a global catastrophe on Earth (moreover, primarily on the Moon, in contrast to a famous Chinese project with the code name ""1000 Chinese on Mars", the purpose of which is

[23] See (Executive Order, 2020; Krichevsky & Bagrov, 2019).

[24] See (Krichevsky, 2019; Krichevsky & Bagrov, 2019; Medvedev, 2019; Zeleny & Mitrofanov, 2015).

[25] See (Krichevsky, 2020).

to create a colony of people on Mars for the subsequent return to Earth and restoration of humanity after a global catastrophe on Earth"[26]).

Second stage. Total inclusion of the Moon, its space economy in the economy of the earthly civilization of humanity since the 22nd -23rd centuries.

Third stage. Creation of an autonomous cosmic civilization — cosmic humanity with a permanent life of people on the Moon since the 23rd — 26th centuries.

Risks and restrictions in the process of Moon exploration: political, economic, technological, military, biomedical, social, sociocultural, environmental, etc. Their management is of particular importance for the safety and survival of people on the Moon including its colonization and reproduction of people in the future.

"An academician of the Russian Academy of Sciences Nikita Moiseyev, after speaking at the Polytechnic Museum of Moscow (1999), when answering my question about further space exploration by humans, resettlement beyond Earth, said that it was a damping process: human existence and long life further than the Moon were impossible. We are earthly creatures, and in order to live in space, it is necessary to become different, but these creatures will no longer be people. Consequently, further than the Moon, Space can be mastered only by using automatic machines (here is not a quote, but the meaning of what was said is stated, *authorial*)" (Krichevsky, 2020: 41).

Thus, our "lunar future" is unstable and contradictory: the Moon as a new fulcrum can "invert" Earth and the fate of human and humanity, become a new "assemblage" and unity point for humanity on Earth and in space, using fundamentally new technologies to open a "window of opportunity" and a new space for the future cosmic human and humanity. Nevertheless, it may turn out to be a limit for the expansion and evolution of earthly human, provoking catastrophic scenarios of destruction and degeneration of "traditional" human, owing also to the negative impact of the environment during long life on the Moon. Otherwise, after a person is supplemented with anthropomorphic and other robots, cyborgs, they will be replaced with a quasi-man, posthuman, "cybernetic immortal man" or "universal man," etc.[27]

3.2 Unified super global project "Moon Exploration"

The superglobal project "Moon Exploration," proposed by the author in 2018 (Krichevsky, 2018: 98-99), covers the entire set of projects for Moon exploration and will be implemented by humanity for centuries, up to its full development (optimistic forecast).

The purpose and super task of a super global project: full inclusion of the Moon in the sphere of space activities for research, usage of its natural resources, resettlement of people, development of new technologies, equipment, vital systems, safety, and for expansion to Mars, etc.

This super global project needs to be implemented in a "comprehensive" setting, according to the first balanced scenario in the form of three stages described in Section 2 "General model of the process of Moon exploration."

It is necessary to go to deep space, to Mars, etc. through the exploration of the Moon: making imminent its incorporation into the space economy in addition to the earthly one, as well as into the structure of the Earth's protection system from an asteroid-comet hazard (it is to be created in the Earth + Moon space), etc.

[26] After Boris Chertok (Cosmonautics, 2010: 29), cited by: (Krichevsky, 2020: 36).

[27] See (Krichevsky, 2020).

It is advisable to use the experience of the Moon research throughout the 20th-21st centuries, new knowledge, technologies, projects, and capacities. Not only the leading space states can be the leading actors in the process of Moon exploration, but also new space communities, associations, unions, e.g., the World Space Union, which will be created under the auspices of the United Nations in the paradigm of "united humanity" (the author proposed this idea in 2019).[28]

To implement the super global project "Moon Exploration," first it is necessary to create new "rules of the game," institutions of society, technology, including those for life and safety of people on the Moon. It is advancing further on — reliable, effective communications, interaction with Earth, scientific, industrial activities based on the local resources, then — permanent bases, human settlements on the Moon, organizing usage, protection, restoration of the environment, taking into account the characteristics of the Moon, near-Earth, and near-Moon spaces, using new environmentally friendly, clean technologies and projects.[29]

3.3 Environmentally friendly technologies and Moon exploration projects

Methodological aspect. The author has purposefully researched environmentally friendly, clean, "green" technologies and Moon exploration projects since 2018.[30]

Environmentally friendly technologies and projects — meeting environmental standards or even outstripping them, not harmful to the environment, human life and health, or having less negative impact when compared to others.

The classification of environmentally friendly, clean technologies and projects for Moon exploration, taking into account their intended use, covers the entire spectrum of space activities and includes the following main sections: 1) exploration of the Moon and near-Moon space; 2) transport; 3) creation of infrastructure on the Moon; 4) energy (both for Earth and the Moon); 5) support of people's life and safety; 6) extraction, processing, and use of natural resources; 7) protection and restoration of the environment; 8) preservation of natural and cultural heritage.

Historical aspect. The source of research into the greening process is disclosed in the publications on the exploration of the Moon, patents and projects, a significant part of which is available on the Internet. The source base has been compiled, including more than 100 publications and about 100 patents and projects related to Moon exploration in Russia and the world throughout the 20th -21st centuries. Currently, systematization is carried out, and the most important ones are identified and investigated.

Practical aspect. The study of environmentally friendly, clean technologies and projects is necessary for the greening of the process of Moon exploration, environmental assessment, and correction of space projects and programs in Russia and in the world. Until present, environmentalization of space activities in the study and exploration of the Moon has not been given due attention. However, there are many examples of environmentally friendly technologies and projects worthy of study and active practical use.

Examples of environmentally friendly, clean technologies and Moon exploration projects developed throughout the 20th - 21st centuries. Five important examples can be singled out:[31]

1. *"Space elevator."* There are many projects and technologies of creation, including those based on cable systems. The project of the "Earth — Moon" transport

[28] See (Krichevsky & Bagrov, 2019).

[29] See (Krichevsky, 2018, 2019).

[30] See (Krichevsky, 2019).

[31] See (Krichevsky, 2019: 22-23).

system is of particular importance. Moreover, the upper terminal of the elevator is fixed on the Moon, and the lower is above Earth, above the dense layers of the atmosphere. The authors of the project are Alexander Bagrov, Andrey Bagrov, Vladislav Leonov, Russia, 2012.[32] Unlike other projects of space elevators created on Earth, "tied" to it and intended mainly for its maintenance, the new project is focused on Moon exploration. However, as with all space elevators, there are risks of collision of space debris with structural elements, damage and destruction of the elevator.

2. *Solar power station on the Moon.* "Lunar Ring" made of solar panels (~ 400 km wide, ~ 11000 km around the equator of the Moon), Shimizu Corp., Japan, 2013. This ambitious, innovative project aims to fully provide all civilization on Earth with clean electric energy received from the Sun on the Moon and its constant transmission to Earth. Its implementation is planned since 2035. Its focus is on "aiming for a new sustainable society through a paradigm shift on energy. There is a shift occurring from the existing paradigm of conservation of the limited resources on Earth to the concept of producing nearly limitless clean energy, and freely using the abundance of clean energy ... The Sun's energy is perpetual and will not have an adverse impact on the Earth's environment, no matter how much energy we use. The massive energy of the Sun will give us a beautiful Earth and an abundant lifestyle in the future" (LUNA RING).
3. *Creation of structures on the Moon from local resources (regolith).* 3D printing technology. Since the 2010s, such promising technologies and projects are being developed in the USA, EU, Russia, China and other countries.[33] "Multi-dome lunar base being constructed based on the 3D printing concept. Once assembled, the inflated domes are covered with a layer of 3D-printed lunar regolith by robots to help protect the occupants against space radiation and micrometeoroids" (Spall, 2018).
4. *A promising version of the lunar base with artificial gravity identical to Earth's gravity.* GraviCity centrifuge of AVANTA Company, Alexander Mayboroda, director of Company, Russia (2014-2019). Variants of a constant lunar base in the form of a centrifuge are proposed. The project of the lunar base "Barmingrad," developed in the USSR in the 1960-1970s, became the prototype for a number of ideas and structural elements of this project.[34] "A lunar colony on the basis of a lunar base with artificial gravity provides conditions for people's life ... without restrictions on the duration of their stay, until the establishment of a settlement with colonists who arrived for permanent residence without returning to Earth. ... Long-term colonies suggest a family way of life for their inhabitants ... the birth of people beyond Earth and the appearance of the first "cosmic human" and then a new "cosmic race" become highly probable. From an economic point of view, a base with artificial gravity solves the problem of reducing the extremely high costs of delivering crews to the Moon and returning them to Earth" (Mayboroda, 2019: 43). This project includes technologies for protection against radiation with a regolith layer, artificial magnetic fields similar to the earthly ones, etc. At the same time, the project implementation, reliable and safe operation of the centrifuge base

[32] See (Patent, 2012).

[33] See (Krichevsky, 2019; Krichevsky & Bagrov, 2019; Mayboroda, 2019).

[34] See (Krichevsky, 2019; Merzhinov, 2018; Mayboroda, 2019).

on the Moon will require simultaneous creation of two systems: the main and the backup, necessary to replace the main one during the repair period and in other situations.

5. *Space reserves on the Moon.* The project of zoning of the Moon surface and near-lunar space, also including libration points in the Moon-Earth system, with the allocation of territories, spaces for wildlife conservation in the environment, with a regime of restriction or a complete ban on technical activities and nature management in order to preserve the integrity and purity of the natural environment, to protect and conserve unique objects of natural and cultural heritage, including artifacts and monuments of science and technology on the Moon related to the history of its development. This must be done by analogy with the approaches, rules, and experience in creating and operating nature reserves and other protected natural territories on Earth.[35] There are new ideas and technologies for protecting the environment of the Moon and its usage, including for the preservation of unique artifacts, objects and copies, archives of the natural and cultural heritage of terrestrial civilization in special storage facilities on the Moon, under its surface, in the structures made of solid basalts. Exceptional stability of lunar constructions from local solid basalt lets create on Moon extremely reliable storage of cultural values of mankind, — after (Krichevsky & Bagrov, 2019: 43-47).

Why do we need the Moon, what are the risks, what do we want to get from Moon exploration, and how can we get it? What will we gain and lose without going to the Moon? What new problems and prospects can appear during the development and permanent life of people on the Moon? How to control the exploration of the Moon? These and other issues will be discussed and solved by humanity in the process of total exploration and colonization of the Moon, developing and correcting knowledge, attitudes, ideas, concepts, projects, technologies, and activities on Earth and in outer space.

Today it is obvious that in moving from Earth to outer space, humanity needs a new fulcrum and a new cutting edge, which the Moon naturally becomes.

Moon exploration can unite humanity, give a new chance to the earthly human of a Homo sapiens species and our civilization to survive on Earth, and create a "cosmic" human and "reserve" cosmic humanity beyond Earth, and then become a full-fledged cosmic civilization.

Main conclusions

1. A brief review of the history and periodization of the process of research and exploration of the Moon was made, as well as an analysis of the prospects for total Moon exploration and colonization by humanity in the future global paradigm was performed.
2. Moon exploration in the 21st century is becoming a priority for space activities of the leading space states and the world community, one of the main directions of the new space exploration strategy to be developed.

[35] The first publications of the author devoted to it dated back to 2003-2012, after (Krichevsky, 2019: 23).

3. There were proposed: a new "comprehensive" concept of Moon exploration; a concept of total Moon exploration and colonization, including a general process model, a general super global project, and environmentally friendly technologies.
4. Humanity needs to combine efforts and resources, jointly explore the Moon according to a general super global world project, new "rules of the game," including political, economic, technological, military, biomedical, sociocultural, environmental, and other aspects, preservation of natural and cultural heritage.
5. It is necessary to develop and adopt a new lunar social contract — an international agreement on the exploration of the Moon, a unified strategy for Moon exploration as a part of a general strategy for space exploration balanced with the solution of terrestrial problems.
6. There is a need to create "reserve" humanity on the Moon for the survival of the human species of Homo sapiens and restoration of humanity in the event of a global catastrophe on Earth.
7. For effective Moon exploration and maintaining a balance with the environment, it is necessary to develop and use fundamentally new environmentally friendly technologies and projects.
8. It is proposed to create an International Institute for Moon Exploration and its laboratory on the Moon as part of the first international lunar base.
9. It is necessary to organize interdisciplinary studies of the philosophy and experience of Moon exploration, followed by the use of their materials and results in science, education and practice.

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