Nuclear explosive technologies are a powerful accelerator of extraterrestrial industry

Alexander Mayboroda, MSC, December 28, 2023

Abstract: The prospects and economic benefits of implementing Krafft Ehricke's concept of using industrial nuclear explosions for the industrialization of the Moon are considered. Calculations of the cost of producing oxygen on the Moon on an industrial scale are provided. It is shown that a price of about 1 dollar/kg of oxygen and a production volume in the proportion of 1 million tons of oxygen per 8 Mt of industrial nuclear charge power are achievable. The possibilities of implementing this technology under existing treaties on military and peaceful industrial nuclear explosions, and the Outer Space Treaty are analyzed. It is shown that the nuclear industrialization of the Moon solves the problem of building space solar power plants, including at the Lagrange point between the Sun and the Earth as a space system for regulating the thermal regime of the Earth's atmosphere.

Key words: Moscow Treaty of 1963, Nuclear Test Limitation Treaties of 1974, Treaty on Peaceful Industrial Nuclear Explosions of 1976, Comprehensive Nuclear Test Ban Treaty (CTBT), Outer Space Treaty, basalt thermolysis, lunar oxygen, nuclear pulse engine, gas-phase nuclear jet engine, global warming, space power plants.

Introduction

In 1963, the USA, USSR and Great Britain signed an agreement banning nuclear explosions in three environments: space, atmosphere and on Earth. Tension in the world from the expectation of a nuclear apocalypse subsided, but the agreement caused deep disappointment among specialists working on the peaceful use of nuclear weapons in space. Work on the Orion project, which represented the development of a nuclear pulse engine using low-power nuclear charges, was stopped, and the development of a project to use industrial “underground” nuclear explosions on the Moon for large-scale production of oxygen and metals from lunar rocks was frozen. Thus, the treaty banning nuclear explosions in outer space stalled space expansion and locked humanity on Earth.

Many pioneers of astronautics, in particular Krafft Ehricke, believed that it was nuclear pulse rockets that would ensure the conquest of the solar system. Freeman Dyson, the key developer of the Orion project, defined the possible results of the project as follows: “to Mars in 1965, to Saturn in 1970!” In our time, research bases and colonies should have appeared on the Moon, Mars, on the satellites of Jupiter and

Saturn and large asteroids. The cessation of the use of nuclear weapons in space made all this impossible.

The detailed concept of industrial development of the Moon by Krafft Ehricke [1] also remained a pure idea. His concept was based on the most effective technologies, such as transport rockets with pulsed nuclear engines, and thermonuclear charges detonated to thermolyze lunar rocks to produce oxygen and metals. Oxygen is needed to fuel chemical rockets, and metals are needed for the lunar industry.

Krafft Ehricke dreamed that the treaty would be amended to allow the development of pulsed nuclear propulsion systems and the use of nuclear explosions for industrial purposes, but politicians went even further in their prohibitionist activities and in 1996 created the Comprehensive Nuclear Test Ban Treaty (CTBT). Most states have signed and ratified the treaty. And now, finally, Russia has withdrawn its ratification of the CTBT. This event may contribute to the Russian cosmonautics becoming a leader in the process of industrialization of celestial bodies based on the concept of Krafft Ehricke [2]. The concept of nuclear industrialization of the Moon and other celestial bodies has every reason to be considered as an integral part of the national space development project, which must be adopted before July 1, 2024.

At present, there are no serious legal obstacles left to the use of peaceful industrial nuclear explosions in the surface layers on the Moon and other celestial bodies. “The multilateral Treaty Banning Tests of Nuclear Weapons in the Atmosphere, Outer Space and Underwater, concluded in Moscow in 1963, did not cover underground nuclear explosions for any purpose, and the multilateral Treaty on the Non-Proliferation of Nuclear Weapons, which entered into force in 1970, did not cover the use of nuclear explosions for peaceful needs" [3]. As a result of negotiations from October 1974 to May 1976, a new agreement was signed.

The treaty reaffirms the right of the USSR and the United States to conduct peaceful nuclear explosions at any place under their jurisdiction or control, outside the boundaries of test sites designated by the Treaty Limiting Underground Nuclear Tests of Nuclear Weapons of 1974 (thus, all underground nuclear explosions conducted outside national nuclear test sites are considered underground nuclear explosions for peaceful purposes). The parties also agreed to further consider the issue of conducting separate peaceful explosions with a yield of over 150 kilotons (but after the signing of the document such explosions were not carried out).

The document officially came into force on December 11, 1990 (almost 15 years after signing). The Treaty on Underground Nuclear Explosions for Peaceful Purposes is closely related to the Treaty on the Limitation of Underground Nuclear Tests of Nuclear Weapons of 1974 (they are called “threshold” treaties because they do not prohibit, but only limit the power of explosions). Both documents entered into force simultaneously. In addition, the 1976 treaty cannot be terminated earlier than the 1974 treaty. Currently, both documents remain in force, since the Nuclear Test Ban Treaty (CTBT), designed to replace them, signed in 1996, has not yet entered into force.

In the USSR in 1965-1988, 124 peaceful explosions were carried out, during which 135 nuclear devices with a yield of up to 140 kilotons were used.

Current treaties prohibit nuclear explosions in space, but do not prohibit peaceful industrial explosions on celestial bodies, since the concept of “space” used in treaties is traditionally interpreted as extraplanetary space and/or as space outside the atmosphere [4]. Thus, there is no direct ban on explosions in the depths of celestial bodies, since the concept of “space” does not apply to them.

There is also an outer space treaty (Treaty on the principles of the activities of states in the exploration and use of outer space, including the Moon and other celestial bodies), but its content in the context of the considered agreements on underground testing of nuclear weapons and permits for peaceful explosions of industrial nuclear devices indicates the absence restrictions on the implementation of the Krafft Ehricke project.

Article IV of the Outer Space Treaty states that parties to the Treaty undertake not to place into orbit around the Earth any objects containing nuclear weapons or any other weapons of mass destruction, or to install such weapons on celestial bodies, or to otherwise place such weapons in outer space. . The Moon and other celestial bodies are used by the parties to the Treaty exclusively for peaceful purposes. The creation of military bases, structures and fortifications on celestial bodies, the testing of any types of weapons and the conduct of military maneuvers are prohibited. The use of military personnel for scientific research or any other peaceful purposes is not prohibited. The use of any equipment or means necessary for the peaceful exploration of the Moon and other celestial bodies is also not prohibited.

Article IV is not violated in cases of peaceful use of nuclear explosions. In the context of the 1976 treaty, industrial nuclear devices are not weapons, and industrial nuclear explosions are not weapons testing.

In addition, it is possible to completely eliminate the conversion of industrial nuclear charges into combat ones under the following conditions.

1. The means of delivering charge from the Earth to the Moon are such that they are structurally incapable of entering back into the atmosphere without destruction.
2. Delivery of industrial nuclear charges to the Moon is carried out in separate parts - in a disassembled state, by separate spacecraft.
3. Charges are assembled directly in the well - in a chamber for placing the charge, located at a depth of thousands of meters, at least before lowering into the well.
4. Industrial nuclear charges after assembly are immediately disposed of and are not stored longer than the time required to complete the operation after assembly in the well.
5. International observers have technical means that are capable of remotely blocking and/or destroying a charge in case of deviation from the standard procedure.

6. Eliminate the delivery of nuclear fuel from Earth - deliver only safe thorium-232. Use a breeder reactor in which thorium-232 is converted into uranium-233, which is not suitable for creating long-term storage charges.
Finally, any state party to the Treaty may propose amendments to this Treaty. As a last resort, any state party to the Treaty may notify of its withdrawal from the Treaty. Such withdrawal shall become effective upon the expiration of one year from the date of receipt of this notice.

Let's consider what new opportunities space exploration is gaining thanks to alien peaceful industrial explosions.

Lunar industry technology

Currently, the cost of delivering cargo to the Moon, at best, is about 100 thousand dollars per 1 kg. Delivery prices of more than $1 million/kg are normal. The smaller the rocket, the higher the unit delivery cost. It is clear that against the backdrop of such prices, there is constant talk about the impracticality of exploring the Moon and other celestial bodies. However, calls to curtail manned space exploration under the pretext of exorbitant costs are only partially justified - it is only reasonable to talk about the impracticality of space exploration based on chemical rockets. It is precisely this technical basis in the form of ineffective chemical rockets that must be dismantled and, in return, the astronautics must be revived on the basis of pulsed nuclear rocket engines and industrial underground nuclear explosions on the Moon, Mars and other celestial bodies.

At the same time, chemical rockets can find a second wind if rocket fuel, primarily the oxygen component, is produced on the Moon and Mars. As Krafft Ehricka showed, solar energy is ineffective for large-scale production of fuel and structural materials from lunar raw materials. Industrial scale means production volumes of over a million tons per year, which is not yet possible for solar energy. It is possible to quickly create a rocket and fuel industry on the Moon, as Krafft Ehricka showed, only with the help of industrial underground nuclear explosions. The Moon is a dead celestial body, with a deadly background radiation from the solar wind and galactic rays, constantly bombarded by asteroids and space rocks. The power of asteroid impacts sometimes exceeds the power of nuclear charges.

Erice reasonably notes that if explosions of thermonuclear or nuclear charges are carried out at a sufficient depth, in the thickness of the lunar rocks, the surface natural environment of the Moon will not suffer in the least.

Underground nuclear explosions that prevent radiation from reaching the lunar surface do not pose a threat to the lunar ecosystem, even if it existed. But the ecosystem as such is simply absent on the Moon. Paradoxically, an artificial ecosystem on the Moon in the form of separate centers of life - colonies - can be quickly and inexpensively created, and maintained only with the help of industrial nuclear explosions.

In a dead lunar world, hostile to life from Earth, nuclear energy helps create life - the radioactive atom becomes “green”.

The sublunar explosion will release a large amount of oxygen: its content in lunar rocks reaches 40%. If oxygen is removed from the blast cavity quickly enough, rich metal ores will form in the natural lunar rocks surrounding the cavity. Under Earth conditions, such technology cannot be used due to the danger of causing damage to nature. The moon seems to be specially created for the development of explosive technology on it. Unlike living earthly nature, dead lunar nature is not sensitive to the “polluting” effects of industry. Thus, thanks to a fundamentally new technological factor, the energy sector of the lunar industry is closely linked with its raw materials sector.

An assessment of oxygen production using the Krafft Ehricke technology in accordance with the known data on underground nuclear explosions [5;6;7] gives the following figures. To obtain oxygen, it is advantageous to use charges of medium and high power, preferably about 1 Mt. This reduces radioactive contamination of products due to the minimized use of fissile nuclear materials - most of the energy is released through nuclear fusion. Such thermonuclear explosions are considered “clean”.

With an explosion of such power at great depths in basalt, the radius of the evaporation zone is 20 m, in which the mass of evaporated basalt is 90,600 tons. The oxygen content in the evaporated stone and thermal decomposition of oxides is 36,000 tons. Taking into account the release of oxygen in the melting zone surrounding the evaporation zone, an additional 12,200 to 56,600 tons of O2 may be released.

Behind the melting zone there is a hot solid-phase zone of crushing and crushing. It can also release oxygen during the decomposition of iron oxide FeO. The decomposition of FeO can produce a minimum of 50,000 tons of additional oxygen from the evaporation and melting zones. Total allocation: from 98,000 tons to 143,000 tons per 1 Mt. On average - 120,000 tons of O2.

Thus, with an annual consumption of thermonuclear charges with a total capacity of 8 Mt, the volume of oxygen production by the lunar industry will reach 1 million tons. The scale of production can increase quite quickly as the demand for rocket fuel for refueling spacecraft outside the Earth grows. Large consumers of lunar oxygen will be companies implementing plans for the colonization of Mars and other celestial bodies. Another larger consumer will be companies operating in near-Earth space, for example, building satellite solar power plants to supply the Earth with clean energy and/or protect the planet from excess solar radiation in the event of irreversible consequences from the greenhouse effect.

A schematic diagram of the process is shown in Fig. 1 (stages 1, 2, 3 and 4). To prevent intintense reoxidation of metals and silicon, oxygen must be removed from the explosion cavity as quickly as possible. For this purpose, Ehricke proposes using a channel drilled in advance, running from the surface of the Moon to an initial cavity located at the required depth, into which a nuclear charge is placed. A bridge of exactly the calculated thickness is left between the initial cavity and the lower end of the channel.

During an explosion, this jumper is instantly destroyed, and hot oxygen rushes upward through the channel. Reception and treatment facilities and oxygen storage tanks must be constructed in advance above the upper mouth of the canal. However, this is not the best solution.

Ehricke's technology can be improved. In Fig. 1 (steps 5 and 6) shows the process optimization flowchart. The vertical arrangement of charges with simultaneous or sequential detonation of nuclear explosive devices, preferably of varying power, will lead to instant collapse of cavern roofs and early formation of a collapse column, whereas this usually takes a relatively long time, which leads to loss of oxygen as a result of metal oxidation. As a result of colder masses of dust and crushed rock falling into the explosive cavities with a mixture of evaporated metals and hot oxygen and the expansion of gases, the temperature inside the resulting mine will quickly drop. This will prevent re-oxidation of silicon and metals. The oxygen and melt at the bottom of the mine will also be separated by the collapsed rock. If there are no cracks exposed to the surface, the shaft can be used for long-term storage of oxygen, which is consumed as consumer demand increases. After a few years, metals and silicon can be extracted from the artificial deposit.

It should be noted that only a few elements have maximum resistance to induced radioactivity: hydrogen, helium, beryllium, carbon, oxygen, lead. In this regard, oxygen from the nuclear storage cavity (after purification from radioactive dust in cyclones) does not pose such a danger as, for example, air nitrogen, which is very sensitive to induced radiation.

The depth of a underground explosion under lunar conditions for a charge with a power of 1 Mt should be 3000 m from the surface, which is 2.5 times greater than on Earth. For a charge with a power of 400 kt, the depth will be 2250 m. With a charge power of 9 kt, the depth will be 625 m.

Drilling equipment for laying charges on the Moon has a small mass if you use the long-known percussion-rope drilling method. In ancient China, wells were drilled to a depth of more than 1200 m; bamboo tools and manual labor were used to drill them. This method, in an improved form, is still used today. A tripod with an electric winch and a drilling tool weighing 1200 kg are required.

Experts believe that it is more profitable to drill hard rocks using the percussion-rope method even to depths greater than 1000 m, and they note that the mechanical speed of impact drilling in very hard rocks is close to the speed of rotary drilling, and sometimes even equal to it; at the same time, the cost of impact drilling under these conditions is 2.5 times less than for rotary drilling. New methods have been developed in which the mechanical drilling speed increases by 2-10 times compared to the speed of rotary drilling. For lunar conditions, the shock-rope method is the best.

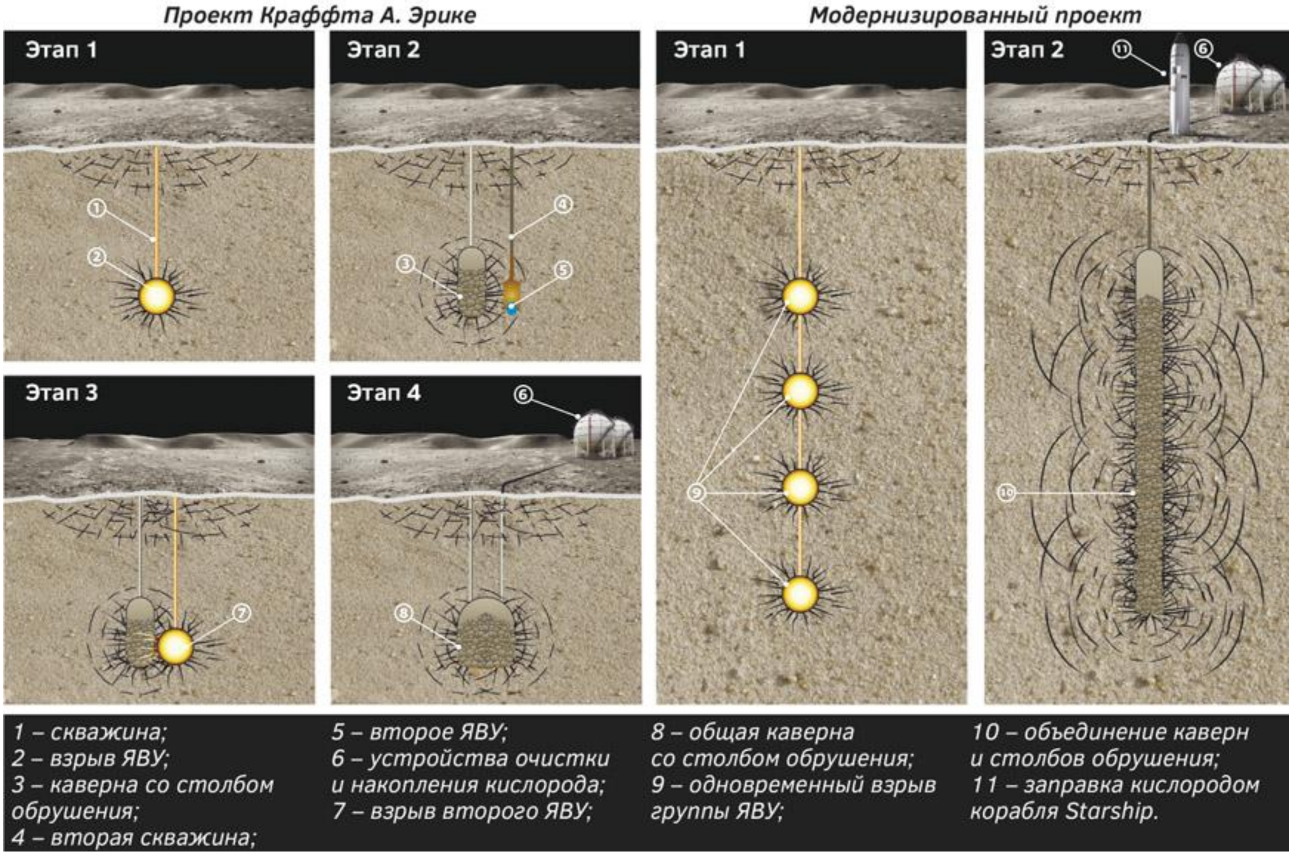

Fig. 1. Explosive technology for extracting oxygen from lunar rocks. Old and upgraded projects.
1 – bore; 2 – explosion of a nuclear charge; 3 – cavern with a collapse column;
4 – second well; 5 – second nuclear device; 6 – oxygen purification and accumulation devices; 7 – explosion of the second nuclear charge; 8 – common cavern with a collapse column; 9 – simultaneous explosion of a group of nuclear charges; 10 – combination of caverns and collapse columns; 11 – filling the Starship with oxygen.

Economics of the lunar industry

You can estimate the cost of producing oxygen using the Krafft Ehricke method at current prices. As a prototype of an industrial charge, we will take the foreign aviation thermonuclear bomb B-61. Its diameter is 34 cm, which corresponds to the task of delivering it to the lunar depths through a borehole. Other parameters: length – 3.6 m; weight – 324 kg, which is convenient for delivery from Earth to the Moon. Explosive power adjustable. Maximum explosive power - presumably in various modifications it is either 340 kt or 400 kt. Minimum – 0.3 kt.

In 1996 prices, the B-61 cost $4.9 million [8]. At the present time, the cost of B-61 is equal to 28 million dollars. To obtain 1 million tons of oxygen (as established in the above text), the required power must be at least 8 Mt. According to these conditions, detonation of a B-61 type charge with a power of 400 kt will create 50 thousand tons of oxygen, the cost of which will be $0.56/kg. This is 180 thousand times less than the cost of delivering oxygen to the Moon using the traditional method!

It is also necessary to take into account the costs of delivering a thermonuclear charge, drilling equipment and a station for pumping, purifying and storing oxygen. However, these are not fixed values - they decrease as the Moon becomes nuclear industrialized.

Today, the delivery of cargo to the Moon is, at best, 100 thousand dollars per kg. And tomorrow, with the industrial production of oxygen on the Moon and the supply of lunar oxygen to reusable shuttles, the price will drop by orders of magnitude. Currently, the delivery of a B-61 type charge to the Moon will be maximum - 32 million dollars. And tomorrow, when filling the Luna-Earth Orbit - Moon shuttles with lunar oxygen, it will cost less than 2 million dollars.

Delivery of drilling equipment will cost more – around $300 million at current prices. However, this equipment can be used many times, dozens of times. Therefore, the contribution of drilling equipment to the cost of a single explosion will not exceed $30 million in the form of depreciation, since the drilling rig will be used on at least 10 more wells.

The contribution to costs from oxygen storage tanks and the purification system will be insignificant since the resulting oxygen is stored in an “underground” tank, and not in external containers - it is consumed to refuel the shuttles not at once, but in portions. The cost of delivering the storage and treatment complex is estimated at $300 million.

Thus, taking into account the indicated main cost factors at the first stage, the total costs will be $390 million per single explosion. If the mass of oxygen produced is 50 thousand tons, then the cost of oxygen will be $7.8/kg.

In the future, thanks to the reduction in the cost of flights to the Moon, when the price of delivering cargo from low-Earth orbit to the Moon is reduced from 100 thousand dollars / kg, for example, to 10 thousand dollars / kg, the total cost of a single explosion will drop to 64, 2 million dollars. In this case, the cost of oxygen will be 1.3 dollars/kg.

The next round of price reductions for flights to the Moon to $5,000/kg will reduce the total cost of a single explosion to $46.1 million. This will reduce the cost of oxygen at lunar gas stations to $0.92/kg.

[It should be noted that with explosions with a power of 1 Mt, the cost reduction will be more significant. The fact is that the cost of nuclear charges does not grow linearly with their power. For example, as practice has shown, an increase in power from 1 kt to 1 Mt (that is, a 1000-fold increase) only led to a threefold increase in the cost of a charge. Therefore, the use of charges with a power of 1 Mt instead of charges with a power of 0.4 Mt will not lead to an increase in specific costs by 2.5 times. Accordingly, unit fixed costs are likely to decrease from $0.56/kg to $0.23/kg, and taking into account the variable component, the cost of oxygen will decrease from $0.92/kg to $0.37/kg].

Technological perspectives – explosive and non-explosive nuclear technologies

Unfortunately, rockets on the Moon can only be fueled with oxygen, and fuel - hydrogen or methane - will have to be delivered to the Moon. Rockets with an oxygen-hydrogen engine must bring 20 kg of hydrogen from Earth for every 100 kg of lunar oxygen (hydrogen in rocket fuel is taken in excess). Rockets with an oxygen-methane engine should deliver up to 27.9 kg of earthly methane (also in excess) for every 100 kg of oxygen. This somewhat reduces the weight of the delivered cargo, but is still beneficial. It is also more profitable and simpler than producing hydrogen from lunar water.

Back in the last century, engines using aluminum powder as fuel were tested. Oxygen engines with fuel based on powdered magnesium and silicon were also proposed. These three types of fuel are produced on the Moon during underground thermonuclear explosions. Deposits of these substances can be developed approximately 10 years after their formation at the site of explosions, which will undoubtedly contribute to reducing the cost of lunar rocket fuel.

The costs of creating wells can also be reduced, using the space method, which is feasible on the Moon, but inaccessible under terrestrial conditions. The initial drilling of wells can be carried out by a flow of high-density bodies, for example, from iron [9]. In Fig. Figure 2 shows a schematic diagram of such a space-based method for drilling wells.

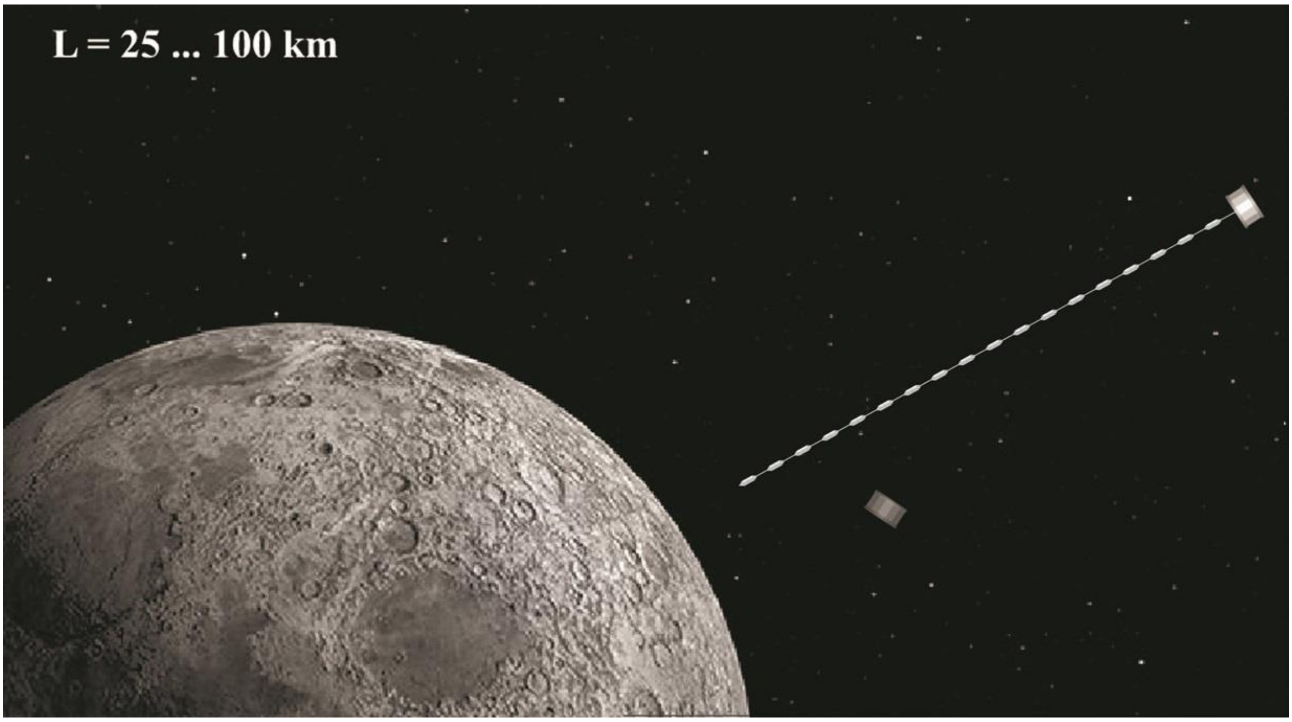

Fig. 2. A chain of strikers deployed as it approaches the Moon.

Initially, the chain of impactors can be launched from Earth orbit. Then, at the stage of advanced industrialization, launch can be carried out from the Moon by rockets filled with lunar fuel and impactors made of lunar iron. It is also permissible to use basalt impactors, although this requires an increase in their mass. Impactors may contain portions of highly volatile substances. The diameter of the wells is an order of magnitude larger than the diameter of the impactors, so gases from highly volatile substances carrying finely crushed basalt from the well should not be blocked by the flow of impactors.

Complete cleaning of the well should be carried out in the traditional way, as in conventional percussion-rope drilling - using a bailer. A conventional bailer is a pipe with a valve suspended on a cable, which, when it hits the bottom of the well, captures cuttings and then rises, bringing the cuttings to the surface. Since the sludge must be moistened with water, which is scarce on the Moon, the bailer must be modernized - the valve must be replaced with an auger, and the longitudinal movement of the bailer must be replaced with rotation of the auger.

At the stage of developing artificial deposits of metals generated by thermonuclear explosions, with a total mass of hundreds of thousands and millions of tons, it is possible to create a system for launching spacecraft using the energy of nuclear explosions as in the Orion project. The project can be modified - nuclear explosions are used as an energy source, carried out in steel chambers made of lunar metal, similar to the large explosion chamber “Sphere” of the Explosion Center of the Joint Institute for High Temperatures of the Russian Academy of Sciences. The weight of the camera with stand is 850 tons.
In such explosion chambers, nuclear mini-explosions with a power of less than 0.001 kt are carried out outside the natural environment, hermetically sealed, isolated, without dispersing fissile materials and chain reaction products. Unreacted fissile materials are not lost and, after purification, are reused, which has a positive effect on the economics of using small nuclear charges.

The chambers are equipped with windows, which are sealed with a gas (plasma) seal at the moment of explosion. Radiation from the explosion is let out, and the fission products and unreacted uranium or plutonium are locked in the chamber. Fissile materials can be reused after purification. The nuclear charges used are charges designed during the work on the Orion project. Most of their energy will be released in the form of radiation focused in one direction. Orion charges emit infrared radiation. Low-power charges that generate directed X-ray radiation can also be used. The radiation causes ablation of the ship's push plate, which creates jet thrust with a high specific impulse.

Industrialization of the Moon could lead to the creation of a space transportation system based on chamber nuclear explosions that generate infrared focused beams and X-ray laser radiation. The lunar transport system for launching spacecraft will ensure speeds of about 20-30 km/s and higher.
Schematic diagrams of the creation of jet thrust by radiation pulses from explosion chambers on the Moon are shown in Fig. 3.

At the same time, launches with speeds of tens of km/s should be rare. Basically, the modernized Orion system should be operated for launches at speeds of about 2.5-3 km/s. This speed is sufficient for ultra-economical delivery of cargo to near-Earth space and to alien colonies.

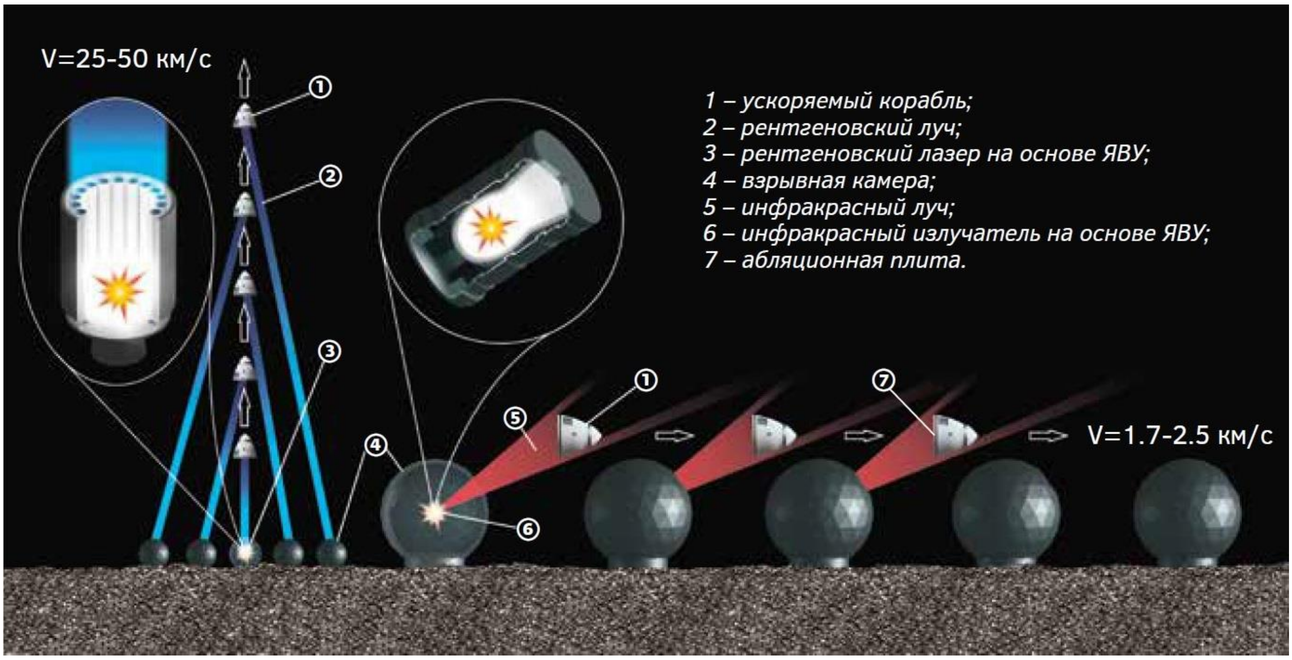

Fig. 3. Launch of Orion-type cargo ships using focused radiation from chamber charges.
1 – accelerated ship; 2 – X-ray; 3 – X-ray laser based on nuclear explosive devices; 4 – explosion chamber; 5 – infrared ray; 6 – infrared emitter based on nuclear explosive devices; 7 – ablation plate.

Krafft Ehricke recommended some innovative transport schemes - to launch transport ships from the surface of the Moon, he proposed using the pressure of gases heated during an “underground” nuclear explosion and directed into a kind of cannon barrel. The system proposed by Krafft Ehricke can be conditionally called a nuclear artillery accelerator. Such a nuclear-artillery spacecraft accelerator ejects fission products and the remains of unreacted uranium or plutonium into outer space at a speed significantly exceeding the lunar first space speed, which eliminates the problem of radioactive contamination. However, low-power nuclear explosive devices used in the accelerator are characterized by a low percentage of expensive fissile material used - most of it does not participate in the chain reaction and is dissipated during the explosion.

Taking into account the political requirement to eliminate explosive processes, an alternative system of non-explosive use of nuclear energy is proposed. In it, the acceleration of the apparatus in the accelerator tube is carried out not by a gas flow emanating from the explosion chamber, but by an open-cycle gas-phase nuclear jet engine (GNRE) installed on the apparatus. An intractable problem of using a HFNR is the removal of unreacted nuclear fuel along with the working fluid (up to 50%), which greatly reduces the energy and economic characteristics of the rocket. Such engines are extremely simple, unlike closed-cycle turbojet engines, but are not used for economic reasons, not technical ones. R&D on GFNR fuel elements of a similar design was carried out in the USSR [10].

The essence of the proposal is that rockets are accelerated by a gas-phase engine only in a sealed pipeline (with a fast-acting airlock outlet), and the nuclear fuel carried out by the working fluid remains in the pipeline and is not dispersed in outer space. Removing nuclear fuel from a pipeline is possible in various simple ways. After cleaning, the collected fuel can be reused.

Thus, the lunar space zone creates conditions for the implementation of the simplest GFNRD. To remove cargo from the Moon at the second escape velocity, the linear dimensions of the pipe of such a rocket exhaust accumulator will be about 3 km, if its acceleration is at the level of solid propellant rockets, such as Sprint or Rainboat.

It seems promising to explore the use of an open-circuit GNFRD as a breeder reactor in which thorium-232 is used as a raw material, converted into uranium-233, in order to produce nuclear fuel in quantities exceeding the needs of the GNFRD itself. This will eliminate the need to deliver nuclear fuel from Earth. At the same time, uranium-233 is not suitable for creating long-term storage nuclear charges (compared to standard weapons-grade uranium-235) due to the difficult to separate impurity of uranium-232, the decay products of which create hard penetrating radiation. Uranium-232 has the strongest heat generation, which disrupts the stability of produced nuclear weapons.

Schematic diagrams of the Krafft Ehricke nuclear explosive accelerator and a non-explosive rocket launch system with an open-cycle HFNR are shown in Fig. 4.

Non-explosive nuclear technologies are known, which are also capable of transforming lunar rocks into oxygen, metals and silicon with high productivity rates.

Fig. 4. Non-explosive transport technology - launching cargo ships with an open circuit gas-phase nuclear rocket engine. A method for isolating and storing exhaust from an open-circuit gas-phase reactor.

1 – explosion chamber; 2 – accelerator barrel; 3 – gas-phase pulsed reactor exhaust accumulator; 4 – capsule with cargo; 5 – cargo rocket with an open-type gas-phase nuclear reactor; 6 – gas-phase reactor exhaust accumulator; 7 – gateway.

The design of high-temperature nuclear reactors has great development potential in terms of further temperature increases. The salt and metal coolants used in them make it possible to reach temperatures above the melting and decomposition temperature of basalt.

There is a well-known project for an “atomic needle” - a miniature reactor with a diameter of only 60 cm. The reactor should be enclosed in a heat-insulating case made of beryllium oxide with a heavy tungsten tip. The operating principle of the “atomic needle” is as follows: high temperatures created in the reactor (over 1100 °C) will lead to the melting of rocks on which the reactor is placed with a tungsten tip, and, accordingly, to the immersion of the reactor deep into the Earth. At a depth of approximately 32 km, the tungsten tip should separate, and the light reactor floats to the surface, lifting with it samples of material from the depths of the planet.

It is advisable to use a similar device on the Moon for the thermal decomposition of basalt rocks into components - oxygen, iron, other metals and silicon. In reactors equipped with radiation shielding that heat lunar rocks with a heat exchanger with a metal coolant, the resulting metals and silicon will not be subject to induced radiation. The heat exchangers can use the proven coolant Bi-Sn-Pb-Cd with a melting point of about 70°C and a boiling point of 1700°C and tin with the corresponding temperatures of 232°C and 2620°C.

Schematic diagrams of the use of high-temperature reactors for processing lunar raw materials are shown in Fig. 5.

In such a negative scenario, other means of preventing a global climate catastrophe will be required. Among these well-known means is the space temperature control system - a loitering auto-climate regulator. This is a project to protect the Earth from global warming using a large “umbrella”. The project was developed by employees of the Energia rocket and space corporation [11;12].

The main element of the space energy-climatic complex, which regulates the thermal regime of the earth's atmosphere, is a ship with a solar sail - a loitering automatic climate regulator (BARC). It is launched at the Lagrange point between the Sun and Earth (at a distance of 2.57 million kilometers from the planet) and blocks part of the flow of solar radiation.

Two versions of the solar-sailing ship (SPS) BARK have been developed. The simplest option, which reduces the average temperature of the Earth's atmosphere by 0.3°C, has a radius of 220 km, a structure mass of 800 thousand tons and a ballast mass of 2.95 million tons. A total of 3.75 million tons. Another option, representing a space power plant , has a mass of the panel, which reduces the average temperature of the Earth’s atmosphere by 1.5°C, equal to 6 million tons, and the mass of the ship itself (with the panel) is 12 million tons. To be in the libration point zone at a distance of 2.57 million km from the Earth, ensuring a minimum mass of the ship, the ship must be loaded with “ballast” weighing 44 million tons.

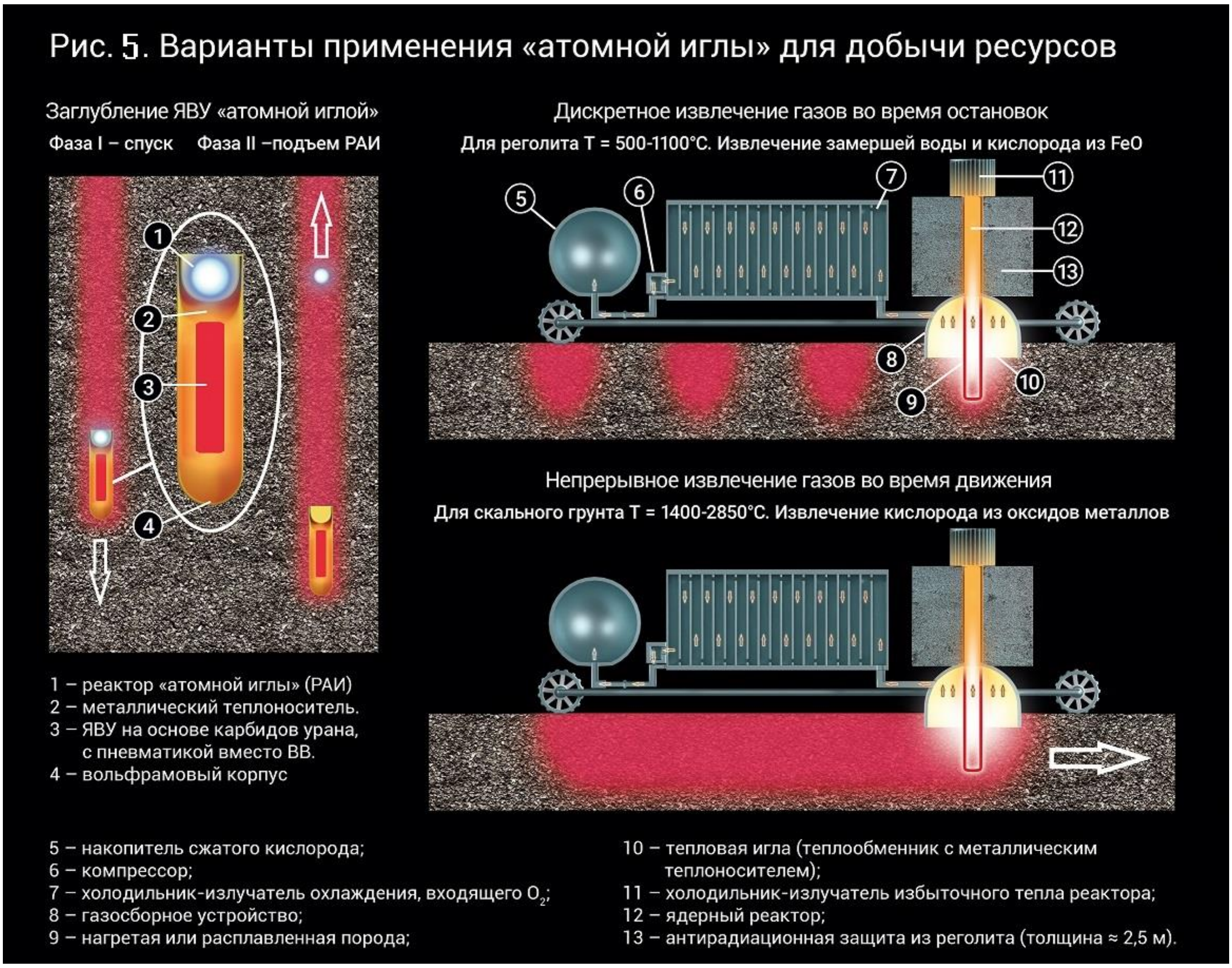

Fig. 5. Non-explosive technology for extracting oxygen from lunar rocks by thermolysis of regolith with heat from a high-temperature nuclear reactor.

1 – "atomic needle" reactor; 2 – metal coolant; 3 – nuclear explosive device based on uranium carbides with pneumatics instead of chemical explosives; 4 – tungsten bod; 5 – compressed oxygen storage; 6 – compressor; 7 – refrigerator-radiator for cooling incoming O2; 8 – gas collection device; 9 – heated or molten rock; 10 – heat needle (heat exchanger with metal coolant); 11 – cooler-radiator of excess reactor heat; 12 – nuclear reactor; 13 – anti-radiation protection from regolith (thickness ≈ 2.5 m).

The simplest version of the complex, if launched in 2070, will be able to reduce the global temperature on the planet by 0.3 degrees Celsius over 30 years. RSC Energia specialists call for the project to be started as early as possible - before the polar caps disappear on Earth. However, it is clear that with existing space technologies, even if a timely decision is made to implement the project, the construction speed will be insufficient and the implementation of the project will require nuclear industrialization of the Moon.

It should be noted that at the stage of multi-year deployment of the BARC complex, as a temporary measure to reduce global temperature, it is advisable to use lunar regolith to create a "solar shield" directly in the upper layers of the Earth's atmosphere. The mass of the atmospheric shield should be 3.14 - 4 times greater than the mass of the flat space shield, depending on the shape of the screen - in the form of a closed ribbon encircling the planet, or in the form of a sphere.

For a screen in the form of a tape, based on calculations by the designers of the BARK complex, it follows that, for example, when the upper layers of the atmosphere are saturated with lunar dust weighing up to 18.85 million tons, with an average particle diameter of 1 micron, it is possible to reduce the average temperature by 1.5 ° C , as when using the BARK complex weighing 56 million tons. One-time resource costs are reduced by 3 times, but due to the descent of dust screen particles to the bottom of the atmosphere, constant replenishment of lunar dust from the upper layers of the atmosphere or a one-time annual replenishment is required. The exact interval is difficult to determine without experiments, since dust provokes the formation of noctilucent clouds at altitudes of 70-95 km, which increases the reflectivity of the atmosphere and prolongs the effect due to the addition of earthly water crystals.

To reduce the average temperature by 0.3°C, the mass of the atmospheric dust screen will not exceed 2.5 million tons, instead of 3.75 million tons for the simplified version of the BARK complex, which is 1.5 times less.

The result is similar to the decrease in temperature during volcanic emissions. However, unlike volcanic eruptions, the process of reducing the light permeability of the atmosphere can be carried out gradually and regulated on the basis of feedback, without the onset of a “volcanic winter”.

A screen weighing 2.5 million tons can be created within 1 year with daily delivery of regolith weighing 6.886 thousand tons. Starship-class lunar shuttle using lunar fuel ivo, is capable of delivering up to 550 tons of regolith per flight. 12.5 flights are required per day. Taking into account the weekly duration of the flight along the Moon-Earth-Moon route, a fleet of 88-90 ships is required. The consumption of lunar fuel will be 5-10 million tons per year with the consumption of nuclear charges with a total capacity of 40-80 Mt.

Lunar dust is discharged tangentially to the conventional boundary of the atmosphere at a speed close to the second cosmic speed and enters the atmosphere at altitudes of 90-110 km, where it is subjected to braking and fragmentation. Taking into account the actual diameter of the particles, which should be less than the calculated one, the mass of the dust screen will be less than the design 2.5 million tons. Nevertheless, the accepted value of the screen mass corresponds to the possibilities of producing lunar rocket fuel by industrial nuclear explosions.

The transfer of lunar dust into the Earth's atmosphere may have the additional beneficial effect of clearing space debris from low orbits, based on a project by Gurudas Ganguli and colleagues at the US Naval Research Laboratory. He proposed a method for cleaning low Earth orbits using tungsten dust [13,14]. Dust must be ejected at an altitude of 1100 km at escape velocity. A dust cloud of tungsten particles will create a spherical shell around the Earth 30 km thick. This will require approximately 20 tons of dust. The size of dust particles is about 30 microns. The resistance of the atmosphere, as well as the action of the planetocentric Poynting-Roberstson effect, will lead to a slow compression of the shell and its approach to the Earth.

In about 10 years, the cloud will drop to a critical height of 900 km, after which the compression will accelerate. A cloud of tungsten dust will slow down small fragments of space debris. Complete cleanup in the low orbit zone will take approximately 25 years. It is believed that dust will not cause much harm to actively functioning spacecraft.

New opportunities created by large-scale production of lunar fuel make it possible to use lunar dust instead of tungsten dust. This will require additional fuel consumption to launch lunar dust into circular orbits and create production on the Moon for sifting regolith and selecting particles of the required size - less than 10 microns. Lunar dust must be consumed in much larger quantities than tungsten, perhaps about 10 thousand tons of dust will be required, but the low cost of its delivery justifies its use instead of tungsten. In the process of delivering 2.5 million tons of regolith, the cost of creating a dust cloud weighing 10 thousand tons to remove space debris is not significant.

Large fragments of space debris will be removed by standard spacecraft using cheap lunar rocket fuel ivo, is capable of delivering up to 550 tons of regolith per flight. 12.5 flights are required per day. Taking into account the weekly duration of the flight along the Moon-Earth-Moon route, a fleet of 88-90 ships is required. The consumption of lunar fuel will be 5-10 million tons per year with the consumption of nuclear charges with a total capacity of 40-80 Mt.

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Large fragments of space debris will be removed by standard spacecraft using cheap lunar rocket fuel.

Conclusions

The principles of creating industry using nuclear energy on the Moon also apply to the industrialization of Mars, dwarf planets and satellites of the giant planets. Outside the orbit of Mars and the asteroid belt, it is almost impossible to harness solar energy. Here, nuclear energy, especially in pulsed-explosive form, is so far the only way to quickly and inexpensively industrialize most of the Solar System. And the atmospheres of the giant planets contain reserves of thermonuclear fuel accessible (to storage devices like PROFAC), which so far can only be used in thermonuclear charges. Thermonuclear reactors, even if they mature to industrial use, will be orders of magnitude more expensive to operate than thermonuclear charges.

The lunar industry, based on new physical principles, can become a springboard for industrially weak countries and overcome the gap in the space race. The simplicity and low cost of industrialization of the Moon based on the nucleization of industry, subject to equal access to the Moon, will ensure equalization of the level of development, if initially not on Earth, then in space. Of course, the successes of nations in the industrialization of the Moon will contribute to their development on Earth and equalize their economic potentials.

It is advisable to consider the project for the nuclear industrialization of the Moon as a strategic plan for the national project currently being developed for the development of the space industry. With the participation of RSC Energia specialists, proactive research should be carried out with the involvement of specialists from the space industry of the BRICS countries.

It is necessary to study the legal need to supplement the Outer Space Treaty with an agreement on peaceful industrial nuclear explosions on the Moon and other celestial bodies, following the example of supplementing the 1974 treaty on military nuclear tests with the 1976 treaty on the peaceful uses of nuclear charges. Currently, there are no direct prohibitions on alien peaceful industrial explosions.

It is desirable to supplement the treaties of 1974 and 1976 with a ban on underground nuclear tests on Earth and direct permission for alien “underground” (subsurface) industrial nuclear explosions.

Movement in this direction can begin today. For example, to begin with, carry out the following experiments:

• tests on the Moon to penetrate a hole with a chain of steel strikers falling at a speed of 2.5-3 km/s;

• pilot testing of the technology of spraying regolith (its analogue) in the atmosphere with satellites to create a protective screen from excess solar radiation;

• and finally carry out a test industrial explosion in the bowels of the Moon.

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