Ecological issues of space industry

S Yu Piskorskaya

Reshetnev Siberian State University of Science and Technology, 31 Krasnoyarsky Rabochy Av., Krasnoyarsk, 660037, Russia

E-mail: piskorskaya.l@rambler.ru

Abstract. The article deals with the negative impact on the ecological situation in the areas of rocket and space activities. It turns out that the fallen modules of carrier rockets and the remaining fuel in them (heptyl) which enters the environment by toxic dispersing in the atmosphere and gets in contact on the ground having a negative effect on the environment. The article presents a comparison of functioning spaceports, especially the advantages and disadvantages of the Baikonur and the Vostochny cosmodromes. As a proposal, a system of permanent monitoring is considered, which allows identifying the parameters of the environment in an open approach to reduce social stress in the areas of activity of the rocket and space industry.

1. Introduction

In recent years, the media have increasingly raised the issues of environmental safety, as well as the protection of the population concerning the use of liquid rocket fuel in the space industry. Information on the negative impact of rocket and space activities on the regional ecosystems leads to the certain social stress among people who live in the territories where the enterprises of the rocket and space industry are located. These people are, on the one hand, in a particular environmental situation, on the other hand, they distrust the official sources of information covering the consequences of the space industry activities.

It is obvious that the long-term activity of the rocket and space industry could not help but affect the environmental pollution of the areas, where the carrier rocket modules have fallen. The consequences of such intervention in the ecosystems of the areas depend on the degree of its impact. So the maximum load is experienced by the areas where the first stages of the carrier rocket have fallen. In places of their modules crash, the earth's cover is subject to mechanical, chemical and thermal damage. As a result, there are violations of soil and plant ground cover, compaction and clogging of soil, formation of craters and fires, soil damage by wheels of heavy equipment used to extinguish fires and evacuate fallen carrier rocket modules, changes in the chemical properties of the soil cover and. As a consequence there is reduction in the number and specific diversity of ecosystems, as well as the optimal ratio of their components.

The assessment of the consequences of such interference in the natural environment is one of the most important tasks of modern science, which, despite the half-century history of the practical exploration of outer space by humanity, is still being formed [1].

It should be noted that the impact of the rocket vehicle on the environmental situation in the areas of separating modules falling is complex. Together with the carrier rocket modules, the liquid rocket fuel enters the ground, the composition and degree of toxicity of which depends on the type of launch vehicle used. The most dangerous for the environment is heptyl. World Health Organization has included this substance in the list of especially dangerous chemical compounds that have a general toxic and skin-irritating effect on the human body. Heptyl is widely used in the space industry both in Russia and around the world, and therefore it can be argued that it affects the environmental safety of a number of countries. Used in propulsion systems of manned ships and automatic satellites, orbital stations and spacecraft, heptyl enters the environment by dispersing it in the atmosphere and in contact with the remains of fuel
on the ground when the fuel tanks fall [2]. Untreated fuel residues and their combustion products enter the atmosphere and water, forming serious biochemical anomalies.

Considering that the space industry and its technological components are a strategically important sector of the economy for Russia, all its environmental consequences require constant monitoring of rocket and space activities, the launches of which are possible from six spaceports. They are the cosmodromes of Baikonur (Kazakhstan), Plesetsk (Arkhangelsk region), Kapustin Yar (Astrakhan region), Yasny (Orenburg region), Svobodny and Vostochny (Amur region). Currently, the most involved are the Baikonur and the Vostochny cosmodromes.

The Baikonur cosmodrome is the first and the largest spaceport in the world, located on the territory of Kazakhstan, created in the USSR in the mid-fifties of the twentieth century and leased by Russia until 2050. It is this cosmodrome from where the first space satellite has been launched, the first human flight into space has been carried out, as well as the first carrier rocket has launched.

Currently, the Russian presence on Baikonur remains an important part of the social, political and economic life of the city of the same name, which is home to more than 70 thousand people, of which almost a third are citizens of Russia. For the term of the lease, the Baikonur complex is endowed with the status corresponding to the cities of Federal importance of the Russian Federation, with a special regime of safe operation of facilities, enterprises and organizations, as well as the residence of citizens. Inside the city there is Russian legislation, as well as Kazakh laws are also applicable to Russian citizens.

Naturally, the functioning of the cosmodrome and the existence of the city now largely, if not completely, depend on Russia. In this regard, the reorientation of Russia to the Vostochny cosmodrome will mean a serious burden on the Kazakh budget. Russian experts estimate that now the Kazkosmos budget contributions to Baikonur facilities are not less than two million dollars. And if Kazkosmos cannot find alternative foreign partners who will provide the spaceport with investments and load it with work, the Kazakh government will face mass migration of citizens to other regions of the country [3, 4]. At the same time, this same social problem is also relevant for Russia itself: the authorities will also need to cope with the relocation of more than twenty thousand citizens.

Given the risks, the Russian and Kazakh parties are looking for ways to deepen mutual cooperation. So, back in the early 2000s, Presidents N. Nazarbayev and V. Putin agreed to build a new Baiterek (Topol) launch pad, from which an eco-friendly Angara launch vehicle could be started. This could become a new "growth point" for the spaceport. In July 2016, it became known that "Angara" will not launch from the "Baiterek" place. Therefore, the threat to the environment of the Kazakh steppe remains the main issue, as the simplified version of Proton, which is the workhorse of the Russian space Agency, most likely, will continue to fly on heptyl [5].

In this regard, the Kazakh authorities raise the issue of environmental safety and protection of people's health, especially after a number of accidents that have occurred, however, the economic benefits from cooperation with Russia still prevail. Therefore, the movement of local activists is increasing, demanding that the government of Kazakhstan take measures, including payment of compensation for environmental damage.

Environmentalists blame Roskosmos for non-compliance with its environmental obligations, as well as the fact that due to the influence of Roscosmos State Corporation and the particular status of the city of Baikonur, it is not possible to prove the damage to people's health and the environment, and, consequently, to achieve compensation. However, the elimination of environmental violations is necessary, as is the need for continuous monitoring of the state of ecosystems in the implementation of rocket and space activities at the Baikonur cosmodrome. Such monitoring is carried out at the regional (the area of the cosmodrome and the areas of fallen carrier rocket modules) and local (the spots of falling of these modules) levels.

Environmental monitoring involves monitoring the content of toxic pollutants and assessing the state of ecosystems in General and their individual components. Moreover, each monitoring level corresponds to specially developed observation programs that are formed according to the principle of choosing priority pollutants and integral characteristics reflecting a group of processes or changes in the composition of substances. The objects of research are more than 40 areas of fallen modules of carrier rocket launched from the territory of the Baikonur cosmodrome.

Twenty-one of these areas are located on the territory of the Russian Federation, their total area is about 35 thousand square kilometers in the territories of nine subjects of the Russian Federation (Novosibirsk, Tomsk, Omsk, Sverdlovsk regions, Altai and Perm regions, the Republic of Altai, Khakassia, Tuva), the rest are on the territory of the Republic of Kazakhstan [6].
In this regard, the need to implement space projects at the Vostochny cosmodrome, on the basis of which Russia will be able to implement a new project of the Angara heavy carrier rocket, more environmentally friendly than the Protons launched from Baikonur, which are charged with toxic heptil, is quite understandable [7].

It should be noted that Vostochny occupies a geographically more favorable location than the existing Russian cosmodromes of Plesetsk and Kapustin Yar, because it is closer to the equator, which provides an increase in launch vehicle speed due to the tangential launch point speed due to the daily rotation of the Earth. In this sense, Vostochniy is slightly inferior to Baikonur (the difference is a little more than six degrees in latitude), however, despite this, experts call them direct competitors. In addition, the location of the Vostochny spaceport in the Russian Far East creates an additional opportunity for the development of this region.

Analysis of the positive and negative aspects of Baikonur and Vostochny operation for Russia showed that the positive aspects of Baikonur should include its location, due to which the modules and debris fall in a deserted area, which does not affect the ecological situation in Russia, but in any case affects the ecology of Kazakhstan. The negative aspects of using Baikonur include the dependence on a foreign state and the cost of technology of the last century.

Let us turn to the analysis of the advantages and disadvantages of the use of the Vostochny cosmodrome. The positive aspects of functioning Vostochny include the advantages of the new technological wave, the lack of rent and freedom of action. The negative is the transfer of environmental burden to Russia, as the areas of falling modules cover the areas of active economic activity, including cities, navigable rivers and reserves. Moreover, it is almost impossible to evacuate the debris of rocket stages and emergency spacecraft from the taiga.

Currently, scientific and methodological approaches are being discussed how to create an environmental monitoring system for the Vostochny cosmodrome. It is noted that this system should become an integral part of the Roscosmos departmental environmental monitoring system, and recommendations have already been developed on the formation of a monitoring program. Studying the features of the impact of rocket and space activity on the environment of a territory, it should be noted that the Institute for Water and Environmental Problems of the Siberian Branch of the Russian Academy of Sciences has been conducting such studies since 1998.

They are talking about complex ecological-biogeochemical and medical-ecological studies of the impact of rocket and space activities on ecosystems and public health.

Since 2010, the named Institute has been involved in the environmental support of the construction of the Vostochny cosmodrome, including, since 2013, in the creation of an environmental monitoring system for its further operation. General analysis of research results 2013-2014 shows that the current ecological situation of the cosmodrome area corresponds to the category of “relatively satisfactory”. The consequences of the negative impact of the construction processes of the cosmodrome facilities on the ecosystems of the region have not been identified. It is assumed that the environmental monitoring system of the Vostochny cosmodrome area should become a component of the Roscosmos departmental environmental monitoring system.

In the structure of Roscosmos, there is a Center for the operation of ground-based space infrastructure facilities, which is the head enterprise for environmental monitoring of the the Baikonur cosmodrome territory and the areas of booster debris landing and missiles launching spacecraft for various purposes from the Baikonur cosmodrome. In general, this center is responsible for conducting departmental environmental monitoring. To implement this task, the company has established the department of environmental safety of ground-based space infrastructure.

Within the framework of some objects of space infrastructure (for example, cosmodromes), systems of industrial environmental monitoring have been formed as a subsystem of departmental environmental monitoring. For example, there is a space center “Yuzhniy” at the cosmodrome Baikonur. It is also planned to create a similar structure at the Vostochny cosmodrome, which should be open enough so that in the future, as new objects are put into operation and their impact on natural environments and components are revealed, this information is available to the general public, removing the negative social assessment in advance. It will also enable interaction with other sources of information, databases, means of their production and processing [8].

The long-term experience of Russian scientists in this field suggests that in order to increase environmental safety in the territories of cosmodromes and the areas of carrier rocket modules falling, further development and improvement of the environmental monitoring system and improvement of the analytical bases and integral indicators of environmental impact are required. This is necessary to ensure
the collection of reliable data sufficient to establish indicators on the basis of which it is expected to normalize their permissible impact on the environment.

It should be noted that in modern science, environmental monitoring is understood as a system of observations, assessment and forecasting of the state of the environment and the environmental situation on the basis of instrumental and other measurements of indicators of the state of objects of environmental monitoring.

Due to the heterogeneity of objects - territories exposed to rocket and space activities - the degree of impact on their components is different. Therefore, the environmental monitoring system pays special attention to the issue of territorial location of observation points. Monitoring spots cover the maximum diversity of areas exposed to space-rocket activities with different levels of impact on them, which helps to assess the degree of change in ecosystems and their components.

One approach to determining the location of monitoring spots can be the zoning of the territories of cosmodromes and areas of impact of the carrier rocket separating modules on the stability of ecosystems and their components by different types and scales of impact. For example, the factors responsible for the resistance of ecosystems to chemical effects can be integrated into three groups.

The first group includes indicators determining the intensity of self-purification of the environment: the degree of dissection of the surface, features of the structure of the territory, characteristics of the surface layer, features of the hydrogeological conditions of the area, meteorological indicators (rainfall, wind speed, etc.).

The second group is the indicators responsible for the possible forms and speed of transformation: soil climate, biochemical activity, the total amount of solar radiation and other factors.

The third group of characteristics is responsible for the possible strength of the fixing of polluting products and includes indicators of soil and rock capacity that can absorb pollutants, redox conditions, mineralogical composition, elemental composition of soils and soils, as well as characteristics of geochemical barriers and biogeochemical specialization of plant communities.

The fourth group are natural factors that contribute to the stability of ecosystems to mechanical damage, these include the strength properties of soils and the nature of the vegetation cover of the territory.

Identifying the ecological parameters of assessing the state of ecosystems, it should be noted that the primary task of environmental monitoring is collecting, analyzing and systematizing information that allows not only to diagnose changes in ecosystems, but also to determine in time the approximation of a certain critical level in their functioning.

In this sense, the optimal selection of indicators and the precise determination of their critical values, in combination with the monitoring time limit, will allow for the timely implementation of all necessary protective and preventive measures [6].

When determining the environmental parameters for assessing the impact of rocket and space activity on the properties of ecosystem components, it is necessary to use generally accepted theoretical approaches, as well as practical results of field and laboratory experiments on modeling pollution of ecosystems with rocket fuel components and their transformation products.

2. Conclusion
Thus, it is too early to say anything about the prospects for environmental safety at the Baikonur and Vostochny cosmodromes with some confidence, since the launch of objects into space must meet, on the one hand, the strategic economic plans for the development of the government, and on the other hand, the environmental safety of all humanity.

However, already now it is possible to state the need and the possibility of organizing environmental monitoring of the territories of cosmodromes and areas of carrier rocket modules falling. This monitoring allows reducing social stress regarding the availability to the general public the information on the environmental problems of the space industry and ways to solve them.

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