**ANNOTATION**

of the dissertation submitted for the degree of Doctor of Philosophy (PhD) in the specialty 8D07105 – "Space Engineering and Technology" by

BEKESHEV YERLAN AKHMEDOVICH

# Development of a technology for detoxifying soils contaminated with the hydrocarbon component of rocket fuel

## Relevance of the study

The rocket and space activities (RSA) of the Baikonur Cosmodrome, taking into account the established long-term practice of supporting the launches of space rockets (SR), eliminating the consequences of space rocket accidents and dynamic observation of adjacent territories, indicate that the system for ensuring environmental safety of the Baikonur Cosmodrome's activities requires constant improvement in line with modern requirements.

One of the key challenges in ensuring environmental safety in Kazakhstan in the area of rocket and space activities at the Baikonur Cosmodrome is the need to neutralize environmental contamination by toxic components of rocket fuels in areas where the separating stages of launch vehicles fall and in areas affected by emergency situations.

The fall areas of launch vehicle separating parts, where toxic rocket fuel spills occur during space rocket stage landings, are found only in the Republic of Kazakhstan and the Russian Federation. Internationally, launch vehicle separating parts land in the oceans.

Due to the intensive exploitation of the Baikonur Cosmodrome in Kazakhstan, there is a massive destruction of natural complexes in the fall areas, which are located in nine regions of our country and have a total area of more than 4.1 million hectares.

Currently, the Russian Federation, as the launching party, leasing the Baikonur complex, does not carry out measures to neutralize the territory of the Republic of Kazakhstan contaminated with toxic rocket fuel, due to the lack of methods and technology for neutralizing soils contaminated with toxic hydrocarbon components of rocket fuel.

Thus, given the functioning of the Baikonur Cosmodrome and the lack of methods for cleaning up rocket fuel from soils in the country, the urgent question of developing an environmentally safe technology for cleaning up toxic hydrocarbon rocket fuels from soils, taking into account the natural and climatic characteristics and soils of Kazakhstan, has become urgent.

**The aim of the study is** to develop an effective and environmentally friendly technology for soil detoxification, contaminated with toxic rocket fuel components.

## Research objectives

1. Research on pollutant behavior and impact:

- study of the stability of rocket fuel – kerosene in the soils of the Republic of Kazakhstan;
- studies of rocket fuel migration in soils;

- study of the phytotoxicity of rocket kerosene;
- microbiological research.

2. Conducting in-kind studies on the disposal of rocket fuel in the positional area of the Baikonur Cosmodrome.

3. Development of technology for detoxification of soils contaminated with the hydrocarbon component of rocket fuel.

**Research methods**

In solving the problems necessary to achieve the stated goal, the following methods were used: standard soil-geochemical, generally accepted ecological and special methods of microbiological research.

**Scientific novelty of the conducted research**

For the first time, a study of the processes of stability and migration of the toxic hydrocarbon component of rocket fuel in various types of soils characteristic of the territory of the Republic of Kazakhstan.

For the first time, a complex of studies was carried out aimed at the phytotoxicity of hydrocarbon rocket fuel in soil samples and microbiological studies on experimental soil samples collected in different regions of Kazakhstan, as well as in a model soil standard.

In addition, for the first time, an environmentally safe method for cleaning soils contaminated with toxic hydrocarbon rocket fuel has been developed, taking into account the specific natural and climatic conditions and the diversity of soil and geographic zones of Kazakhstan.

**Scientific and practical significance of the dissertation work**

Developed environmentally friendly soil detoxification technology based on the association of indigenous strains of microorganisms such as *Acinetobacter calcoaceticus 18, Bacillus sp.20, Micrococcus roseus 25, Candida sp. 12/5,* from contamination by a toxic component of hydrocarbon rocket fuel will help restore the soil and vegetation cover in the territory of the Baikonur complex exposed to rocket and space activities.

Based on the results of the study, Implementation Certificates were received for the "Technology for detoxifying soils contaminated with the hydrocarbon component of rocket fuel" from the Joint Stock Company "Joint Kazakh-Russian Venture "BAITEREK", Moscow State University named after M.V. Lomonosov (Russian Federation), and the Branch of the RSE "Infrakos" in Almaty of Aerospace Committee of the MDDIAI of the Republic of Kazakhstan, JSC "Federal State Unitary Enterprise Center for operation of ground-based space infrastructure facilities" (Russian Federation).

**The main provisions submitted for defense:**

1. The optimal parameters of the technology for microbiological detoxification of soils contaminated with the hydrocarbon component of rocket fuel have been substantiated and experimentally confirmed, including the patterns of its stability and migration in various types of soil, phytotoxicity indicators, characteristics of the microbiocenosis, as well as the potential of indigenous strains of microorganisms as hydrocarbon destructors.

2. The applicability and effectiveness of the association of indigenous strains of microorganisms in detoxifying soil from toxic hydrocarbon rocket fuel under natural conditions at the Baikonur Cosmodrome sites was established.

3. A technology for detoxifying soils contaminated with the hydrocarbon component of rocket fuel has been developed in the form of a draft Technological Regulation for the microbiological detoxification of soils contaminated with hydrocarbon rocket fuel, including sections describing: source materials, measuring instruments, technical and auxiliary devices, raw material consumption rates, a list of regulatory and methodological documentation, the procedure for carrying out detoxification, as well as safety requirements.

**Personal contribution of the applicant**

The author conducted an analysis of literary data on the problem under study, experimental laboratory research in specialized accredited laboratories and field studies at the sites of the Baikonur Cosmodrome positioning area, as well as an analysis of the results of these studies with the writing and design of the dissertation manuscript.

**Testing the results of the dissertation**

The main provisions of the dissertation are presented and published in the following materials:

- XI-International scientific conference "Problems of the evolution of open systems "PEOS-2021"", dedicated to the 75$^{th}$ anniversary of Professor Vyacheslav Mikhailovich Somsikov (2021, Al-Farabi Kazakh National University);

- International scientific and practical conference "Priorities of mechanics and theory of automatic control in the development of space equipment and technologies" dedicated to the 75$^{th}$ anniversary of Professor, Academician of the National Academy of Sciences of the Republic of Kazakhstan and the National Engineering Academy of the Republic of Kazakhstan Moldabekov Meirbek (2022, Institute of Mechanics and Engineering named after academician U.A. Dzholdasbekov).

**Scientific publications**

Based on the research results, 12 printed works were published, including:

Scopus database - 5;

- articles recommended by the Committee for Quality Assurance in Science and Higher Education of the Republic of Kazakhstan (CQASHE RK) – 5;

- articles published in collections of international scientific and practical conferences - 2.

**Volume and structure of the dissertation**

The dissertation consists of an introduction, five chapters divided into subsections, conclusions, a final summary, a list of references, and appendices. It comprises 195 pages, including 61 figures and 54 tables.

**The introduction** presents the relevance of the research and specifies the problem being investigated. It describes the main idea, scientific novelty, and validity of the work, as well as the validation of the results and publication.

**Chapter I** analyzes global trends in hydrocarbon pollution remediation methods. The analysis concludes that, in each specific case, an integrated approach combining mechanical, physicochemical, and biological treatment methods is recommended, ensuring more complete destruction and neutralization of pollutants. The impact of

kerosene on soil systems is determined by regional conditions—soil type, climate, hydrological regime, and biological activity. Therefore, specific, targeted studies are required for each soil and climate zone to identify patterns in kerosene behavior in the soil environment and optimize its neutralization methods, taking into account local environmental factors.

**Chapter II** presents the materials and research methods for experimental studies in laboratory and field conditions. This dissertation utilizes an integrated approach, combining soil geochemical, environmental, and microbiological research methods.

**Chapter III** presents the results. To study the impact of hydrocarbon rocket fuel on soils from the Soyuz launch vehicle side-bodies impact sites, soil samples were prepared, including a model soil standard for experimental work. The stability of hydrocarbon rocket fuel (kerosene) was studied in various soil types, and kerosene was found to be more stable in mountainous brown desert soils. Studies on the migration of rocket kerosene showed that migration in the studied soils is highly dependent on the degree of soil contamination. Increasing the concentration of rocket kerosene leads to its deeper penetration into the soil profile. These results indicate high migration mobility of rocket kerosene in soil. Analysis of the soil microbiological composition, respiration rate, and phytotoxicity revealed that restoration of the microflora of sandy desert soil occurs within the first day, and after 10 days in gray-brown desert soil. The experimental sandy desert soil is not phytotoxic after 10 days, the control soil after 20 days, the experimental gray-brown desert soil is not phytotoxic after 20 days, and the control soil remains phytotoxic.

from soils sampled in areas negatively impacted by rocket and space activities at the Baikonur Cosmodrome. These isolates included microorganisms (*Acinetobacter calcoaceticum-18, Bacillus sp.-20, Micrococcus roseus-25, and Candida sp.-12/5* ) capable of degrading high concentrations of toxic hydrocarbon rocket fuel. The results of a study on the utilization of rocket kerosene by an association of indigenous microbial strains demonstrated complete utilization of rocket kerosene in the soils.

**Chapter IV** presents the results of full-scale experiments conducted at sites located in the Baikonur Cosmodrome's launch site. A comparative analysis of the physicochemical properties of soils before and after full-scale tests shows that full-scale tests do not significantly alter the physicochemical composition of the soil.

Based on the test results, technological conditions for microbiological detoxification of soils at the Baikonur Cosmodrome facilities were developed. Analysis of the results showed that the work was carried out using modern methods. Comparing the obtained results, it can be noted that this work is consistent with modern scientific research on the use of hydrocarbon-oxidizing microorganisms in the remediation of soils contaminated with toxic rocket kerosene.

Field trials of the microbiological detoxification method demonstrate its high effectiveness, allowing for the rapid cleanup of toxic hydrocarbon rocket fuel spills. This method is simple and easy to use, and the results of this development could find practical application in the rocket, space, and oil refining industries.

**Chapter V** presents research on the development of a process flow diagram for the microbiological detoxification of soils contaminated with the hydrocarbon component of rocket fuel, as well as a process flow diagram for producing a dry microbial preparation used in bioremediation. The developed soil detoxification process diagram provides a step-by-step algorithm of measures aimed at restoring the ecological and biochemical properties of the soil cover through bioremediation.

A technology for detoxifying soils contaminated with the hydrocarbon component of rocket fuel has been developed in the form of a draft Technological Regulation for the microbiological detoxification of soils contaminated with hydrocarbon rocket fuel, including sections describing: source materials, measuring instruments, technical and auxiliary devices, raw material consumption rates, a list of regulatory and methodological documentation, the procedure for carrying out detoxification, as well as safety requirements.

To improve the further implementation and application of the technology for detoxifying soils contaminated with toxic hydrocarbon rocket fuel, a dry microbial preparation in tablet form was developed, containing the microorganisms *Acinetobacter calcoaceticus 18, Bacillus sp. 20, Micrococcus roseus 25, and Candida sp. 12/5.* Implementation certificates for the "Technology for detoxifying soils contaminated with the hydrocarbon component of rocket fuel" were obtained from the Joint Kazakhstan–Russian Enterprise "BAITEREK" JSC, Lomonosov Moscow State University (Russian Federation), the Almaty Branch of RSE "Infracos" of the Aerospace Committee of MDDIAI of the Republic of Kazakhstan, and FSUE "Center for operation of ground-based space infrastructure facilities" (Russian Federation).

**The conclusion** reflects the main results and findings of the dissertation.

**The appendices contain**: Implementation reports on the "Technology for detoxifying soils contaminated with the hydrocarbon component of rocket fuel" and Conclusions on the study of crop hazard classes.