Development of a measures complex to reduce the technogenic impact of launches of the promising Irtysh launch vehicle in the impact areas of the Baikonur cosmodrome

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Abstract. Scientific and methodological approaches to minimizing the technogenic impact of launches of the promising launch vehicles of the Irtysh type with the oxygen-kerosene main liquid rocket engines of the Baiterek rocket complex in the impact areas of the Baikonur cosmodrome are considered. The basic directions for the reducing the technogenic impact of the worked-off booster of the first stage of the Irtysh type launch vehicle in the impact areas are: determining the optimal site for the worked-off stages (WS) fall in the selected zones of the impact areas that have the greatest resistance and the minimum cost on the restoration of the soil grounds of the site of the WS fall to its initial state - (A); controlled WS descent after separation from the LV into the designated site of the fall with an accuracy not exceeding the size of the selected optimal site - (B). To solve problems of the direction A, it is proposed to create an additional information and analytical system of the impact area. To solve problems of the direction B, possible design solutions are proposed based on the evaporation of unused liquid fuel residues in the WS tanks, and using the resulting vapor-gas mixtures for controlled WS descent to the dedicated zone of the impact area.

1. Introduction
The operation of the launch vehicles (LV) with liquid rocket engines (LRE) is associated with a negative impact on the environment, which especially appears in the impact areas (IA) of the WS, due to the presence of specific properties of this vehicle: the presence of multi-stage and unused residues of liquid fuel in the tanks and fuel lines. The first property of a launch vehicle with LRE leads to the need to allocate significant areas on the surface of the Earth for areas where the lower WS fall, and for orbital WS this leads to littering of near-Earth space with large-sized potentially explosive space debris. In addition, ensuring the fall of the WS in already designated impact areas leads to a decrease in the output mass of the payload of the LV into the orbits of operation. The second property of the LV with LRE leads to an increase in the likelihood of explosions and fires in the ground areas where the
WS falls, chemical contamination of soils and water sources. All these occurrences take place in the impact areas of the Baikonur cosmodrome. Further development of LVs with LREs, for example, in the USA, goes in the direction of saving lower WS for their reuse, which leads to a sharp decrease in the area of the impact areas. It should be noted that the existing impact areas in the USA, EU, Japan, India are located in the waters of the World Ocean, where issues with the allocation of impact areas are less acute than in Russia and Kazakhstan.

The proposed project considers the evolutionary concept of reducing the technogenic impact of the WS in the impact areas of the Baikonur cosmodrome based on the parallel implementation of two basic directions of reducing the technogenic impact of the WS in the impact areas:

- determining the optimal sites for the WS fall in the selected zones of the impact areas with the greatest resistance to technogenic impact, respectively, the minimum cost of work on restoring the soil grounds of the site of the WS fall to its original state; (A)
- controlled descent of the WS after separation from the launch vehicle in the designated site of the fall with an accuracy not exceeding the size of the selected optimal site (B). To solve problems related to direction A, it is proposed to create an additional information and analytical system of the impact area (IASia), which is a part of the ecological monitoring system of the Baikonur cosmodrome (EMSC). To solve problems related to direction B, possible design solutions are proposed based on the evaporation of the unused liquid fuel residues in the WS tanks, ensuring its fire-explosion safety, and using the resulting vapor-gas mixtures for the controlled WS descent while moving on the descent trajectory to the optimum site located in a dedicated impact area zone.

2. Review of the problem state of technogenic impact in the impact areas of spent boosters of LV stages with the liquid rocket engine.

The problem of ensuring the ecological safety in the impact areas of the WS is becoming increasingly important due to the increasing requirements of national environmental legislation and the claims of society. The main negative factors of the technogenic impact of the WS in the impact areas are [1]: a) mechanical pollution by the WS and their fragments (destruction of the structure and the subsequent dispersion of the parts); b) chemical pollution by spills of unused residues of the liquid rocket fuel components (RFC); c) pyrogenic and thermal effects (fires, explosions).

During mechanical contamination with metal debris and WS fragments, funnels are formed, the soil and vegetation cover is damaged (the humus layer of the soil is especially badly damaged, the projective cover of the phytocenosis and floristic composition changes). Chemical contamination with liquid LPC residues, leading to a high probability of fires, is the most aggressive factor of exposure. The magnitude of liquid residues of RFC for various types of LV can reach up to 3% of the initial charge of LPC and more. Pyrogenic and thermal disturbances of the soil and vegetation cover of the impact area, arising from the fall of the WS, can be real and potential factors during the operation of the LV.

As is known, the vulnerability and stability of a biogeocoenosis in the impact area as a result of the action of negative technogenic factors is determined by the state of its main components — the ecotope (soil, climate, water) and the biotope (vegetation). The soil performs a number of important functions and is a link between the biological and geological cycles of matter and energy, in which, in fact, the processes occurring in it are refracted and reflected. The special properties of the soil cover are expressed in its fertility - the most important condition for the existence of life.

The cardinal minimization of the negative technogenic impact of the WS in the impact area is achieved under the condition of the WS controlled descent to the allocated site of the impact area without liquid residues of the RFC in the tanks and main lines of the worked-off stages. Therefore, to solve the problem of ensuring the ecological safety of the impact area territory during their rational operation, it is necessary to formulate the following basic directions for reducing the technogenic impact:
– determination of optimal sections for the WS to fall in selected zones $S_{w_s}^{opt}$ that have the greatest resistance to the technogenic impact of launches of launch vehicles with the main LREs, respectively, the minimum cost of work $\min C_{\Sigma}^{w_s}$ on the soil restoring of the fall site $S_{w_s}^{opt}$ to its initial state (A);
– controlled descent of the WS after separation from the LV into the allocated site $S_{w_s}^{opt}$ with an accuracy not exceeding the size of the selected optimal site with the complete absence of the liquid residues of RPC in the fuel tank and the main lines of the WS (B).

For the implementation of direction (A), the following factors are considered that determine the resistance of the impact area to the technogenic impact: a) fire safety of vegetation and associated meteorological conditions; b) the condition of the soil cover, including the suppression of fertility and degradation of the soil cover; c) the state of vegetation.

2.1 Fire safety of the territory
The most likely causes of fires are liquid residues of RPC in the WS tanks, which ignite when the fuel compartments of the WS are destroyed at the moment of impact on the ground surface in the IA. A notorious example is the launch of the Soyuz-2.1a launch vehicle [2], when a fire broke out as a result of the fall of the WS with the unused residues of RPC, as a result of which people died. The area of the steppe fire reached ten thousand hectares. The technogenic nature of the fire was aggravated by the conditions of difficult weather conditions (hot weather, wind).

The practice of the LV operation has shown that deflagration and fires, damage of the vegetation cover due to the WS fall occur mainly in the impact areas of the spent boosters of the first WS with oxygen-kerosene main LRE [3]. The probability of occurrence of fires is significantly influenced by [4]: a) the position of a particular area in the altitude-belt spectrum of the territory (length of the snow covered period), b) the nature of the underlying substrates, the angle of inclination and exposure (which largely determine the redistribution of precipitation over the territory), b) the nature of its own vegetation (the presence or absence of rags, the nature of the grass-shrub layer (height, density, the possibility of "drying out").

Fire hazard is determined by such fire and technical characteristics as combustibility; flammability; flame propagation velocity over the surface; smoke forming ability; toxicity [4-5].

Resistance of ecosystems to pyrogenic effects is determined primarily by their ability to ignite and flammability. The formation of a combustible medium is caused by the presence in it of a sufficient amount of a combustible substance - plant biomass, which has various rates of combustion.

As an additional criterion of the second level in assessing the permissible load under mechanical and pyrogenic effects, it is proposed to take into account the rate of phytocenosis restoration after anthropogenic disturbance [6], as evidenced by the dynamics of post-pyrogenic successions [7].

2.1.1 Climatic prerequisites for fires. The risk of fire is determined by a complex of interconnected meteorological elements (precipitation, air humidity, its temperature, etc.).

A period from the moment of a descent of snow cover to the onset of stable rainy autumn weather or the formation of snow cover is considered to be fire hazardous. The risk of fires increases from the northeast of this area to the southwest following the increase in aridity of the climate. During the fire hazardous season, periods of fire highs are distinguished when the number of fires exceeds their average number.

It should be noted that the air temperature is determined at a level of 2 m above the ground. In the lower, near-surface layer of air, the temperature can reach substantially large values. Heating of the soil surface during the daytime is great - the average maximum surface temperature ranges from 48°C to 59°C in July, the absolute maximum reaches 76°C.

2.2. Soil cover
The soil cover includes dozens of soil varieties with different physicochemical properties. Therefore, in order to simplify the work of collecting information and processing it, well-known reference data are used using the soil map of the region.

For assessing and grading the allocation of each site, it seems appropriate to determine soil bonitet [8]. Soil bonitation of the impact area should be carried out according to the standard soil bonitation techniques. The bonitet score of each soil variety is calculated from the percentage of humus in the half-meter layer, and correction factors are introduced for all other properties. The bonitet scale thus obtained is superimposed on the soil map.

Due to the instability of the soil to the mechanical load on the territory as a result of the impact of heavy fragments on the ground, mainly propulsion systems and fuel-pumping units, funnels of different dimensions are formed — 1-20 m in diameter, 0.3-1.5 m deep [9]. As indicators of the resilience of the surface layer and the complexity of its destruction to determine the allowable load to the mechanical impact, accounting of mechanical properties of rocks on a scale of strength is used.

2.3 Vegetation

Plant cover, experiencing a negative technogenic impact, is the main factor in the process of self-purification of the ecosystem. The potential of the vegetation involved in the redistribution and accumulation of RPC depends on a combination of factors such as the type of the plant community, the geochemical conditions of their habitat, proximity to sources of chemical contamination of RPC, the amount of pollutants entering the surface of the vegetation [9].

The main characteristics of any plant community are floristic composition and structure. In addition to indicators of species diversity, the structure of plant communities, phytocenometric characteristics, the indicators of the state of vegetation also include indicators of generativeness and developmental defects of plant organisms [9].

The response of vegetation to the technogenic effect of LV launches is expressed in the assessment of the resistance of plant communities, according to which weakly resistant, stable and highly resistant are distinguished [6]. The potential stability of plant communities is determined by the ecological and biological properties of the plants themselves [11–12]. Restoration of some communities occurs relatively quickly. At the same time, individual communities are characterized by the low annual growth of the phytomass, their self-healing requires a longer period. A distinctive feature of all communities is their poor resistance to fires and, consequently, a long succession period of recovery. To assess the resistance of phytocenoses to a specific technogenic impact, it is proposed to take into account the following parameters: a) density indicators (structure) of the plant community; b) projective cover (the ratio of the area in the landscape); c) phytomass.

2.4 Estimation of economic costs in the impact areas on the implementation of measures to minimize the technogenic effects of the WS impact

The methodology for assessing ecological damage is based on the consistent implementation of the two main procedures: the determination of negative ecological changes and the indetification of its economic equivalent, i.e. the cost of the ecological damage [1].

According to the methodology for determining the payment for environmental pollution, the ecological damage is estimated according to the basic regulatory fees for emissions and discharges of pollutants. The amount of payment for the environment pollution in the impact area for each case of a standard WS fall is determined by the specific impact conditions: a fall with or without destruction, with or without spillage of fuel, volumes of spillage on the ground, discharge into water bodies, emission into the atmosphere, etc.

The total costs of the ecological support for launches and compensation of the ecological damage include the following expenses: charge for the environmental pollution, conducting ecological monitoring, clean-up of the territory, compensation for the decrease in agricultural production productivity and health care spending [1].
For example, in terms of the charge for the environmental pollution, the unit costs for waste disposal (in 1996 prices) were:
- for kerosene T-1 (toxic waste class IV) – 70,000 rubles / ton;
- for asymmetric dimethyl hydrazine (toxic waste class I) – 490,000 rubles / ton.

In the case of cleaning the area, including the collection, detoxification and disposal of residues of RPC and WS fragments, neutralization of the spillage, the costs of eliminating the consequences increase significantly.

For all impacts, sufficiently large payments to environmental authorities are provided. In 1995 prices, the cost of conducting controls in the RP amounted to ~ 107 million rubles per launch [1]. In case that WS fragments get into the settlement, the consequences of all these impacts are more critical, require more rapid measures to eliminate their consequences and, possibly, evacuate the population and carry out various payments for material and moral damage [13].

Thus, the ecological and economic costs for the impact areas of separated stages for the LV Proton type can range from ~ 3% to ~ 35% of the launch cost (based on the launch cost, estimated at ~ 300 million rubles in prices up to August 17, 1998), and these costs significantly depend on the possible payment options for the environmental pollution and environmental management [1]. For LVs like Zenit and Soyuz, using kerosene T-1 as fuel, costs can range from 2 to 21 million dollars per launch in 2017-2018 prices [14-15].

3. Description of CEMS and justification for the creation of IAS_{ia}

3.1 Description of the existing CEMS of the Baikonur Cosmodrome

The CEMS organization is one of the key points in ensuring the ecological safety of rocket and space activities [1]. The purpose of the functioning of the CEMS is to solve the problem of assessing the harmful effects on the environment and forecasting the spread of pollution in areas of rocket and space activities, ensuring minimization of negative technogenic impact, timely preventing irreversible processes of its degradation, identifying impact factors requiring operational intervention - improving rocket and space technology or environmental protection measures.

The information support of the CEMS is presented by the developed databases of ecological data and is implemented by means of geo-information systems related to the modeling and visualization of geographic space and the solution of spatial problems. The main task of the IAS CEMS is the formation of operational information and analytical assessment of the emerging extreme situations (accidents, spillages, etc.) and the making of operational and early decisions on the localization and liquidation (compensation) of ecological damage from the Baikonur cosmodrome activity. In the structure of IAS-CEMS, the following subsystems are distinguished: preparation of initial data for archiving and documentation; planning, accounting and control, analysis and regulation; mathematical and geoinformation modeling; information processing, analysis and decision making; regulatory support.

The visualization of the IAS-CEMS subsystem is represented by the territorial location of the surveyed key areas and the creation of vector layers that have fields filled with information in the structure: impact area number, coordinates of the place and date of fall, coordinates of sampling points, maximum MPC values, excess of standard indicators, used methodology of physical and chemical diagnostics, etc. The main parameters of resistance in the developed system of criteria of potential resistance to the technogenic impact are the indicators of chemical contamination, physical-chemical transformation of RPC, biodiversity reduction and condition of vegetation on the ecosystem and organismal levels [10]. The current IAS is focused on monitoring chemical contamination of territories and practically does not take into account pyrogen-thermal and mechanical effects of RPC. [10].

3.2 Justification for the creation of IAS_{ia}
The process of selecting the optimal sites for the WS fall into the selected IA zones is proposed to be based on the existing CEMS system with the introduction of the developed IAS$_{ia}$, which should analyze data on the soil and vegetation cover, terrain, availability of water sources, meteorological parameters; to classify homogeneous groups of biogeocenosis objects; specify the area of impact of standard WS falls.

IAS$_{ia}$ should perform the following functions:
- accounting of information about lithogenic basis, relief, types of soil (subsystem "Soils");
- preparation of information on the state of vegetation on the basis of archival cartographic data and satellite images (subsystem "Vegetation");
- preparation of information on seasonality and climate data analysis (subsystem “Meteofactors”);
- analysis of fire safety reference data on flammability and ignition parameters (“Fire safety” subsystem);
- accounting and economic evaluation of measures to eliminate the consequences of WS falls in the impact areas;
- classification of homogeneous groups of objects and analysis of the results of impact area zoning.

4. Isolation of sustainable types of operational-territorial unit

The implementation of the proposed method of allocating the optimal operational-territorial unit (OTU) is based on the existing IAS of the cosmodrome. The land plots act as an OTU $S_i$ ($i = 1, 2, 3 N$), and four indicators are proposed as indicators characterizing possible damage from the fall of the worked-off stage into an allocated OTU: a) fire safety $Q_f$ (flammability and combustibility), b) soil strength $Q_s$, c) bonite of soil type $Q_{bi}$, d) state of vegetation $Q_V$ (projective cover, biomass, recovery period).

The selection of the optimal types of OTU provides the following sequence of actions.

1. A grid of $N$ areas with $S_i$ areas ($i = 1, 2, 3 N$) is superimposed on the research area. Each $S_i$ site represents a "mosaic" of areas with a specific ecosystem composition. The dimensions of the $S_i$ areas can be equal or different, which is determined by the characteristics of the selected fall region, the degree of its detail.

2. Based on the analysis of inventory data, physical-geographical and natural-resource maps, IA passports, remote sensing data, ecological impact assessment methods [1] form a database for assessing the values of the criteria entered.

3. Estimation of the values of the introduced criteria $Q_{fi}, Q_{si}, Q_{bi}, Q_{Vi}$ for each site with an area of $S_i$.

3.1 Determination of fire safety criteria $Q_{fi}$

The fire safety of each site of the $Q_{fi}$ territory is composed of the indicators of the flammability potential $\Delta \Pi_{fi}$ (kJ/mol) and the combustibility $Q_{bi}$ (kW/m$^2$) of the dominant plant community [6]:

$$Q_{fi} = m_1 \Delta \Pi_{fi} + m_2 Q_{bi} \quad (1)$$

where $m_1$ [(kJ/mol)$^{-1}$], $m_2$ [(kW/m$^2$)$^{-1}$] are weight dimensional coefficients, which are determined for a specific selected area and are determined in accordance with the methodology, for example, [5].

To estimate the cost of $C_{si}$ funds required to restore the allocated area of OTU $S_i$ from damage caused by fire, the indicator $Q_{fi}$ (1) is multiplied by the value of the cost coefficient $G_{fi}$, which is determined in accordance with [1]

$$C_{si} = Q_{fi} G_{fi} \quad (2)$$

3.2 To estimate the value of the $Q_{si}$ criterion on the basis of the well-known scale [10], the percentage ratio of rock strength is determined with the determination of the weight coefficient of each rock $k_{si}$ and an average value is given
\[ Q_{s_i}(average) = k_{s1}Q_{p1} + k_{s2}Q_{p2} + k_{s3}Q_{p3} + \cdots + k_{sM}Q_{pn} \]  

(3)

where \( M \) is the number of rocks counted in the \( S_i \)-th allocated area.

In accordance with [1], the estimated cost of \( C_{s_i} \) is determined and, accordingly, the estimated cost of repairing damage is calculated by the \( Q_{s_i} \) criterion:

\[ C_{Q_{pi}} = C_{pi} \sum k_{ni}Q_{kni} \]  

(4)

3.3 The \( Q_{bi} \) criterion is evaluated by analogy with (2), (4), and the assessment of the cost of repairing damage according to the \( Q_{bi} \) criterion is:

\[ C_{Q_{bni}} = C_{bni} \sum k_{bni}Q_{bni} \]  

(5)

3.4 The evaluation of the criterion \( Q_{vi} \), characterizing the state of vegetation cover, is an account of the phytomass \( Q_{vmi} \) (cwt/ha) and the projective cover \( Q_{ppri} \) (in %):

\[ Q_{vi} = n_{vi}Q_{vmi}Q_{ppri}, \]  

(6)

where \( n_{vi} [\text{cwt/ha}^{-1}] \) is a weight coefficient by analogy (1) and is determined in accordance with [6].

An additional criterion, \( v_{ri} \), is the rate of ecosystem restoration (in points) after mechanical or pyrogenic impact, is introduced as the monitoring survey materials accumulate [6]. Accordingly, the cost of repairing damage by criterion \( Q_{vi} \), by analogy with (2), (4), (5), can be written in the form:

\[ C_{V_{vi}} = n_{vi}Q_{vmi}v_{ri}C_{nvi} \]  

(7)

4. The total indicator of the cost of recovery of damage \( C_{si} \) in the designated OTU by the \( S_i \) area from the effects of the above facts is the sum of the values (2), (4), (5), (7):

\[ C_{\Sigma i} = C_{si} + C_{Q_{pi}} + C_{Q_{bi}} + C_{V_{vi}} \]  

(8)

5. The choice of the optimal zone \( S_{\text{opt}} \) for fall of WS is performed from the condition \( \min C_{si} \).

5. Ensuring fire-explosion safety and controlled WS descent

5.1 Ensuring fire-explosion safety

After separation of WS from LV in fuel tanks and main lines of WS, unused liquid residues of RFC always remain, which is the main cause of increased technogenic impact on the environment in the IA [16-17]. In this regard, at the design stage and ground-based development of the LV, considerable resources and time are spent on the elimination of non-used residual RFC in the tanks and fuel lines of the LV. The problem of liquidation of liquid residues of RFC is complicated by the fact that they are in an uncertain position in the volume of tanks, in the gas-liquid phase.

In accordance with the proposed technology, ensuring the fire-explosion safety of WS, is achieved by a sequence of the following actions:

– purge of fuel lines, in which the entire mass of RFC, located in the lines, gets into the corresponding fuel tanks;
– submission to the fuel tanks of the required amount of heat to evaporate unused liquid residues of the RFC;
– discharge of the resulting gas-vapor mixture from each tank through the gas-jet nozzles of the control system:
  – in the tanks WS₁ there remains a boost pressure, which ensures the necessary strength of the structure under aerodynamic loading;
  – by the time of the landing of WS₁, all liquid residues should be evaporated, and the vapor-gas mixtures are dropped during the flight of WS₁ on the descent trajectory.

In Figure 1 (a, b), there are 2 options that implement various technologies and circuit solutions for this task for a spent booster of the first stage LV-WS₁. Option 2 is based on the traditional approach, which involves the use of a system for discharging LRE residues through the shutdown LRE, squeeze membrane tanks, using terminal control methods to the fully worked-off the most toxic RFC and the shutdown of the LRE, etc. Option number 1 is based on the evaporation of unused liquid residues of RFC after the shutdown of the LRE. This option provides for the supply of heat to the WS tanks, evaporation of residues of RFC and their further utilization.

![Figure 1](image_url)

**Figure 1.** Technological and circuit options for solving the problem of eliminating unused RFC residues in the tanks and fuel main lines of the LV after shutdown of the main LRE. (a) Traditional version based on the use of proven technical solutions, (b) Proposed option based on evaporation of the residual of RFC.

As follows from the technological solutions given in Figure 1 for the traditional and proposed options, the essential differences are the systems for extracting unused residues of liquid RFC. Common are the need to install the navigation and traffic control systems on WS₁, including: gimballess navigation system (GNS); global navigation satellite system (GLONASS); gasification implementation systems for gasification products (evaporation) – gas-jet system; possible modernization of the LREs for the re-launch on gasified RFC residues.

Regardless of the implementation options for technological, schematic and design solutions, everything leads to the need to create an autonomous onboard descent system (AODS) of spent boosters from the trajectory of lower WS or descent of upper WS from the orbits [18].

### 5.2 The controlled descent of the WS₁

The specificity of using the AODS is that if it is on board of the LV, it is possible to remove one of the most important limitations when calculating the program for the controlling reentry of the LV on the active part of the trajectory (the pitch program) – conditions for the WS fall into the selected IA. The implementation of this requirement leads to a significant reduction in the mass of the payload [16]. One of the main tasks solved by the AODS is the calculation of the WS descent control program,
transferring its motion path from an energetically optimal path leading to the aiming point located at a distance $D_1$ from the start, to the falling path that leads to a selected point located at a distance $D_2$ from the start and located in a dedicated area $S_{opt}^{ws}$ (Figure 2).

Figure 2 shows the scheme of the descent of WS$_1$ from the energy-optimal trajectory of descent to the falling trajectory.

![Figure 2](image.png)

**Figure 2.** Scheme of controlled descent of WS$_1$ to the selected zone: 1 – launch point of the LV; 2 – the active part of the trajectory of the reentry of the LV first stage; 3 – separation of the WS$_1$; 4 – the active part of the trajectory of the re-entry of the LV second stage; 5 – ballistic trajectory of WS$_1$ descent, corresponding to the energetically optimal trajectory of the launch of the LV first stage; the point of WS$_1$ fall is at a distance of $D_1$ from the launch point of the LV; 6 – the falling trajectory of the controlled WS$_1$ descent to the selected zone $S_{opt}^{ws}$, the center of which is at a distance of $D_2$ from the launch point of the LV; 7 – the beginning of the territory of the IA, corresponding to the distance $D_7$ from the launch point of the LV$_1$; 8 – the end of the IA, corresponding to the distance $D_8$ from the launch point of the LV$_1$.

When calculating the programmed motion of WS$_1$, which provides the transition from the optimal trajectory 5 to the falling trajectory 6, respectively, the fall of WS$_1$ into the selected zone $S_{opt}^{ws}$, the center of which is at a distance $D_2$ from the launch point of LV$_1$, corresponding energy resources are required onboard WS$_1$ (available energy reserves) as well as the available time $T$ on the maneuver of the transition from trajectory 5 to trajectory 6.

The energy resources that can be placed when the WS$_1$ maneuver is performed are determined by the amount of residual of liquid RFC in the WS$_1$ tanks after shutdown of the LRE.

The available time for the $T$ maneuver will be:
- From the total time of the passive flight of WS$_1$ along trajectory 6, determined jointly when calculating the program for the LV re-entry and controlled movement of the WS$_1$;
- Time to bring the AODS in working condition, i.e. carrying out a number of operations that provide for raising the pressure of vapor-gas mixtures in the tanks of the WS for their subsequent use as a working fluid in a gas-jet system.

To determine the design parameters of the evaporation system, it is necessary to develop an appropriate design methodology with subsequent experimental verification.

**6. Conclusions**

1. Proposals for the development of a scientific and methodological approach to minimizing the technogenic impact of launches of promising missiles of the "Irtysh" type by oxygen-kerosene main
liquid rocket engines of the Baiterek rocket complex in the impact areas of the Baikonur cosmodrome are considered.

2. The basic directions of reducing the technogenic impact of the worked-off first stage of the LV of the "Irtysh" type in IA are accepted as:

– Determination of optimal sites for the WS fall in the selected zones of the IA with the highest resistance to technogenic impact, respectively, the minimum cost of work on restoring the soil grounds of the WS fall site to its original state - direction A;

– Controlled descent of the WS after separation from the LV in the designated site of the fall with an accuracy not exceeding the size of the selected optimal section – direction B.

3. To solve problems related to the direction A, it is proposed to create an additional IAS, which is part of the ecological management system of the Baikonur cosmodrome. To solve problems related to direction B, possible design solutions are proposed based on the evaporation of unused liquid fuel residues in the WS tanks, ensuring its – fire-explosion safety, and using the resulting vapor-gas mixtures for controlled WS descent while moving on the descent trajectory to the optimum site located in a dedicated IA zone.

4. Within the framework of direction A, criterion assessments have been developed that characterize the main ecological indicators of the IA under study: fire hazard, soil cover, vegetation for subsequent inclusion in the IAS, The objective necessity and the basic provisions for the creation of IAS, which is a component of the ecological management system of the cosmodrome, are shown.

5. Within the framework of direction B, technological, schematic and design solutions to ensure fire safety of the WS based on complete evaporation of liquid residues of RFC in the tanks and main lines of the WS and the possibility of controlled descent of the WS to the recommended site of the impact area are proposed. The practical feasibility of the proposed solutions is shown on the basis of existing and worked-off components and assemblies used in the operation of the LV.

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