Study of thermal effects of electromagnetic radiation on the environment from space rocket activity

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Abstract: *The article presents the results of a study of electromagnetic effects from space rocket activity using the example of the Plesetsk cosmodrome and aviation complex using the example of Ostafyevo Airport. The influence of electromagnetic pollution on the environment is considered; the authors analyze the influence of electromagnetic fields on human health taking into account thermal effects. It was demonstrated that the long-term effect of electromagnetic sources with different wavelengths at moderate intensity causes changes in the irritability of visual, olfactory and vestibular analyzers, as well as development of functional disorders in the nervous system without pronounced changes in endocrine-metabolic processes and blood composition, also trophic disturbance might be present. The authors study in detail the main anthropogenic sources of electromagnetic effects from objects of rocket and space, and aviation activities.*

Key Words: *electromagnetic effect, aviation activities, heat transfer, cosmodrome*

1. INTRODUCTION

In the process of space rocket activities, various specific impacts associated with the operation of production facilities of the ground infrastructure of cosmodromes have a significant impact on the natural environment.

The work of such facilities is accompanied by emissions into the environment of not only nitrogen and carbon oxides, hydrogen sulfide, aerosols of sulfuric and nitric acids, etc., but also by the action of high-intensity electromagnetic radiation, which is one of the most powerful factors that negatively affect the environment and humans, due to continuous exposure and rapid development. It is known that the electromagnetic field has a negative effect on human body.

A large number of studies conducted in Russia have demonstrated that it is the nervous system that is most sensitive to this effect.

At this, the immunity decreases, the change in protein metabolism may occur, there is a certain change in the composition of blood. A person is accompanied by electromagnetic radiation throughout his entire life.

At intensities exceeding $10mV\,t/cm^3$, various thermal effects arise [1], [2], [3], [4], which adversely affect the body.

The most common diseases caused by electromagnetic radiation are diseases of the cardiovascular and circulatory system (30-50%) - these are: atherosclerosis, myocardial infarction. thromboses, liver diseases, eye diseases, mental disorders and oncological diseases [5], [6].

The objective of our study was to study the electromagnetic effects of space rocket and aviation activities under the influence of various thermal effects.

2. MATERIALS AND METHODS

The environmental assessment of the electromagnetic surroundings begins with taking into account different emitting sources, locations and operating hours of emitters, etc. The objects of study can be cosmodromes, airports, high-energy power lines (Fig. 1-3)

Fig. 1 - High energy power lines

Fig. 2 - Cosmodrome

Fig. 3 - Space launches and electromagnetic radiation

As the objects of research, the Plesetsk cosmodrome and the Ostafevo aerodrome were considered [7]. The Plesetsk cosmodrome supports part of the Russian space programs related to the defense, applied, scientific and commercial launches of unmanned spacecraft. It is located in the central part of Arkhangelsk region, stretching from north to south for $45km$ and from east to west for $82km$, its total area is $1762km^2$. From its territory from 1966 to the present, more than 2.000 spacecrafts for various purposes have been put into orbits, about 1.600 launches of rocket carriers and about 500 launches of intercontinental ballistic missiles have been carried out, more than 11 space rocket complexons and 60 types of spacecraft have been tested.

The Ostafyevo airdrome is located 4 km west of the town of Shcherbinka, Moscow Region, $7.5km$ from the Moscow Ring Road and borders the South Butovo area. The airport has been functioning since 1942 and is the property of the Ministry of Defense of the Russian Federation and Gazprom. The main types of aircraft based at this aerodrome are aircrafts: Yak-42, Yak-40, An-24, Ln-74, Mi-8 helicopter, as well as foreign vessels: Falcon-900, V-734.

3. RESULTS AND DISCUSSIONS

The main sources of electromagnetic radiation in areas of operation space rocket equipment (SRE) are radio systems operating in the UHF and microwave bands that have very high power, up to $1000kW$ at impulse. Such frequency ranges are characterized by transfer of electromagnetic field energy into other forms of energy, for example, into thermal energy [8], [9], especially in biological tissues. This transition happens with very high efficiency.

To study the thermal effects, it is necessary to know the general principles of schematization of bodies and sources involved in heat transmission; the location and shape of sources; the law of distribution of intensity; the velocity of the source; the source operation time. To make schematization of thermophysical properties of processed and tool materials; and Schematization of the geometric shape of bodies, as well as boundary and initial conditions.

Heat transfer and distribution is a complex phenomenon, the implementation of which in each particular case is associated with three elementary methods of heat transfer diverse in their physical nature: thermal conductivity, convective heat transfer, and thermal radiation. The distribution of heat by thermal conductivity depends on physical properties of the body: in gases, heat transfer by thermal conductivity occurs as a result of collision of molecules with each other; in metals, by diffusion of free electrons and elastic vibrations of crystal lattice; in liquids and solid dielectrics - by means of elastic waves (elastic vibrations of crystal lattice). An electromagnetic field is transformed into thermal energy by convective heat transfer - the process of heat transferal when moving macroscopic volumes of gas or liquid from a region with one temperature to a region with different temperature. Convection is always supplemented by thermal conductivity. In engineering practice, heat transfer is of primary interest, which is understood as convective heat transfer between the flow of liquid or gas and the surface of a solid. This process is most frequently described by the Newton-Richman equation (Eq. 1):

$$Q = \alpha F(t_f - t_w) \tag{1}$$

where F is the heat transfer surface, m^2, t_f, t_w are the temperatures of the fluid and the wall, K or ℃, α is the heat transfer coefficient, $W/(m^2K)$. In this case, determination of *the heat transfer coefficient*, which is the amount of heat given off or received by a unit of heat transfer surface F at a temperature difference between the liquid and the wall $1K$, is of great importance.

The heat transfer coefficient α be subject to a large number of factors: the shape and size of the body, the mode of movement, the velocity and temperature of the liquid, its thermophysical properties [10], [11], [12], [13], [14], [15].

A special effect on the human body makes the thermal radiation - this is the process of propagation of thermal energy by means of electromagnetic waves. Through thermal radiation, a double conversion of energy occurs: the thermal energy of the radiating body passes into radiant and, conversely, radiant energy, when absorbed by the body, passes into thermal energy. At a given temperature, the absolute black body emits the biggest heat flux. The value of its density can be determined by the law of Stefan-Boltzmann (Eq. 2):

$$q = \varepsilon \cdot \sigma_0 T^4 \tag{2}$$

where $\sigma_0 = 5.67 \cdot 10^{-8} W/(m^2 K)$ is the radiation constant of the absolute black body.

The density of the heat flux emitted by non-black bodies can be estimated by the formula (Eq. 3):

$$q = \varepsilon \cdot \sigma_0 T^4 \tag{3}$$

where ε is the degree of blackness. Its value is $0 < \varepsilon < 1$ and is found experimentally or using a reference book.

Through radiant heat transfer between two bodies, they simultaneously irradiate each other. The resulting heat transmitted by radiation from a body with a higher temperature to a body with lower temperature can be found by expression (Eq. 4):

$$Q_{12} = \varepsilon \cdot \sigma_{rc} T_2^4 \tag{4}$$

where F is the mutual irradiation surface; σ_{rc} is the reduced radiation constant.

The effect of microwave radiation on biota of natural complexes can be estimated via the radiation intensity, which is expressed in terms of power flux density. Thus, in the areas of command and measurement complexes (CMC) of the Plesetsk cosmodrome, an abnormal radio wave propagation is possible, called the overreaction, which is most frequently observed in the summer both in the morning and in the evening.

The environmental effects of microwave radiation are dependent on frequency and power [16], [17], [18], [19]. Low-intensity electromagnetic radiation with power flux density of $0.5\ mW/cm^2$ in the UHF range is characteristic of natural sources, for example, galactic radio emissions that have a stimulating effect on plants and lead to increased bio-productivity of the ecosystem. For high-power microwave radiation of other frequencies, the environmental consequences could be negative. With intensive irradiation, photosynthetic activity decreases in the leaves of trees, as well as an increase in the frequency of chromosomal abnormalities and decrease in germination of seeds. Nonetheless, biota is also characterized by adaptation to microwave radiation. Furthermore, the intensity of microwave radiation from the radio systems of the cosmodrome decreases depending on the distance to radiation source. The operating frequency ranges of radio engineering systems of cosmodrome command and measurement complexes are close to the frequency ranges of galactic radio emission with wavelength of $18\ cm$, i.e., $1612, 1665, 1667, 1720\ MHz$. Furthermore, the power flux density at a distance of dozens of meters is already reduced.

CMC of Plesetsk have electromagnetic radiation with a pulse power of $50\ kW$ at frequency of $2.6\ GHz$. Numerous sources verified, that the disorders caused by exposure to electromagnetic fields are manifested primarily by the higher nervous activity and bioelectric activity of the brain, as well as disrupted endocrine, immune and reproductive systems of man. Clear reactions of brain tissue cells have been demonstrated when modulating microwave fields of $150 - 450\ MHz$ with frequencies from 1 to $20\ GHz$. At the intensity of microwaves $0.1 - 1\ mW/cm^2$ there was a release of calcium ions from the brain tissue, which impedes the normal development of bones for children and adolescents.

There was also a leak from the cells of hemoglobin, the respiratory pigment of the blood, which provides oxygen transfer from the lungs to tissues. This biological effect of microwaves is explained by the existence of thermal effects arising at intensities of more than $10\ \mu W/cm^2$ [1], [5], [6]. Thermal effects should be investigated using methods of mathematical modeling and experimental research of thermal processes in solids, liquids, and gases. During the study of effect of electromagnetic radiation of the rocket and space activities on the environment, *thermophysical analysis* of radiation and its influence on health should be carried out.

Initially, we need to find the number and location of heat outflow sources in the system or subsystem and set the operating time and power of each of the sources. Then we need to determine the size and configuration of sites or volumes within which heat outflow sources operate and establish the laws of flux density distribution for each outflow source. As a result of these studies, a structural diagram of heat transfer can be developed. Unfortunately, not only people at work on radiating equipment are exposed to radiation hazards, but also people who, for whatever reason, find themselves in the radiation area of antennas. Such situations arise when CMC of the cosmodrome is improperly located in relation to the places where people are. Consequently, the external border of the sanitary-protective zone of Plesetsk cosmodrome is defined at height of $2m$ from the surface of the earth. Permissible exposure limit of EMF for personnel does not exceed $10\ \mu W/cm^2$ and is established within a radius of $350m$ from the phase center of the antenna post. And the construction restriction zone is the territory immediately adjacent to the external border of the sanitary protection zone, where the magnitude of the electromagnetic fields does not exceed the maximum permissible limits established for personnel. The density of the power flux from the radiating CMC antennas raised to sufficient height at a distance of $50.400m$ does not exceed several dozens of mW per $1cm^3$.

At the cosmodrome, the Kama-N complex is employed for external trajectory measurements when launching a space rocket. It is designed for trajectory measurements in active mode according to signals of the repeater, the building restriction zone is set within a radius of $700m$ with the construction height limit as $25m$. Major sectors of work are located in distance from constantly operating buildings. Though, the professional activities of cosmodrome specialists are accompanied by technogenic electromagnetic radiation, pose a hygienic problem. The frequency ranges from $30kHz$ to $300GHz$ account for the largest part of personnel hygiene load.

The highest power flux density of microwave radiation is possessed by tracking stations for deep spacecraft with high-apogee artificial Earth satellites (AES).

The location of the centers of long-range space communications at relatively low latitudes and their significant dispersion in longitude provide the maximum visibility of spacecraft and augmented accuracy in determining the flight path based on the results of navigation measurements.

The results of measurements near EMP sources on board of various aircraft have demonstrated that the radiation intensity ranges from 100 to 1000 watts. Sufficiently high levels of radiation intensity can be generated in the zone of intersection of electromagnetic radiation from several radar stations.

From year to year, the power resource of the radar is growing. The increase in the power of electromagnetic energy generators, particularly for military aviation, increases by 30% every 5 years, therefore, within radius of up to $50m$ from some stations, the radiation intensity can reach from 400 to 800 W/m^2.

Periodic exposure of a person to electromagnetic field to leads to persistent changes in hormonal status and genetic structure. The most intense electromagnetic fields affect organs with a high content of water. Thus, with increasing of exposure to anthropogenic electromagnetic emissions, various ophthalmic diseases were observed, up to complete loss of vision. Overheating is especially detrimental to tissues with underdeveloped vascular system or insufficient blood circulation - these are the brain, eyes, kidneys, stomach, gall and bladder.

The development of eye diseases, burns of the cornea and especially cataracts is one of the specific lesions caused by electromagnetic fields of radio frequencies in the range from $300MHz$ to $300GHz$.

The prolonged influence of EMR of various wavelength ranges at moderate intensity causes a change in excitability of visual, olfactory and vestibular analyzers; as well as the development of functional disorders in functional nervous system, with mild changes in endocrine metabolism and blood composition, which is characterized by acute headaches, increased or decreased pressure, decreased heart rate, and psychological disorders; also possible are trophic disturbances – which includes a decrease in body weight, brittle nails and hair loss.

At airports, the electromagnetic environment is caused mainly by the radiation of powerful radar stations, these include ground-based surveillance radar stations operating in Very High Frequency and Ultra High Frequency ranges. There are national and international standards for EMF levels, depending on the distance to the population of the nearby area and to the place of work.

4. CONCLUSIONS

Intensive space exploration can lead to very noticeable effects on near-Earth environment. First of all, this concerns not only pollution of the environment through emissions of rocket fuel combustion products during launch of rocket vehicles, but also harmful effect of electromagnetic radiation on human health.

At present, the electromagnetic effect on people and environment has progressed from “probabilistic” to existent. And this took place with the introduction of industrial inventions in the area of electromagnetic fields, as well as the influence of electromagnetic radiation. Radiation sources whose wavelengths in the natural environment did not exist have come to existence.

Any device that generates or consumes electrical energy is a source of electromagnetic radiation. It is not only television and radar stations, high-voltage power lines of industrial frequency, X-ray, plasma and laser installations, atomic and nuclear reactors, thermal industrial plants and much more, but also electromagnetic radiation can be caused by anthropogenic sources of electromagnetic effects from space rocket and aviation activities. Everything that is unnatural has become a source of pollution, and at the same time a concept has emerged - “electromagnetic pollution of the environment”.

There even emerged the concept of “electromagnetic smog”. Which implies negative effect on living organisms of low-frequency and super-low-frequency radiation from devices that produce, transmit or consume electromagnetic energy.

It is characterized as multifactor effect, that is, the impact of several sources simultaneously. The measurement results at the Ostafyevo airport have demonstrated that the produced fields of electromagnetic radiation do not affect the areas of production facilities, but thermal effects have a negative effect.

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