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Chromosomal instability in rodents caused by pollution from Baikonur cosmodrome

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Abstract An assessment of the health status of ecosystems exposed to man-made pollution is a vital issue for many countries. Particularly it concerns the consequences of contamination caused by the activity of the space industry. Each rocket launch is accompanied by the introduction of parts of the rocket propellant into the environment. This study aims to scrutinize the effect of the components of rocket fuel on the induction of lipid peroxidation and chromosomal aberrations on rodents inhabiting the area exposed to pollution from Baikonur cosmodrome. The results showed the increase of the level of lipid hydroperoxide and malondialdehyde in the livers of *Citellus pygmaeus* Pallas and *Mus musculus* L., which indicates an augmentation of free radical activity and DNA damage. The cytogenetic analysis of bone marrow cells revealed that the frequency of chromosomal aberrations was a few times higher in the rodents from contaminated territory. The signs of oxidative stress and high level of chromosomal aberrations indicate the environmental impact of the cosmodrome, and its possible toxic and mutagenic effects on ecosystems.

Keywords Rocket · Cosmodrome · Contamination · Rodents · Lipid peroxidation · Chromosomal aberrations · DNA damage

Abbreviations

UDMH	Unsymmetrical dimethyl hydrazine
NDMA	Nitrosodimethylamine
ROS	Reactive oxygen species
LHP	Lipid hydroperoxide
MDA	Malondialdehyde
NO	Nitric oxide
PLO	Product of lipid oxidation
SH-group	Sulfhydryl group

Introduction

An evaluation of the genetic consequences of environmental pollutants is one of the most pressing issues of the present time. Almost all environmental pollutants are potentially dangerous factors that can have a negative, multi-level impact on an organism. The polluting agents can induce qualitative and quantitative disturbances in ecosystems thus affecting the viability and adaptation ability of natural populations (Cotman and Zagorc-Koncan 2005; Medina et al. 2007; Yadav and Jha 2013).

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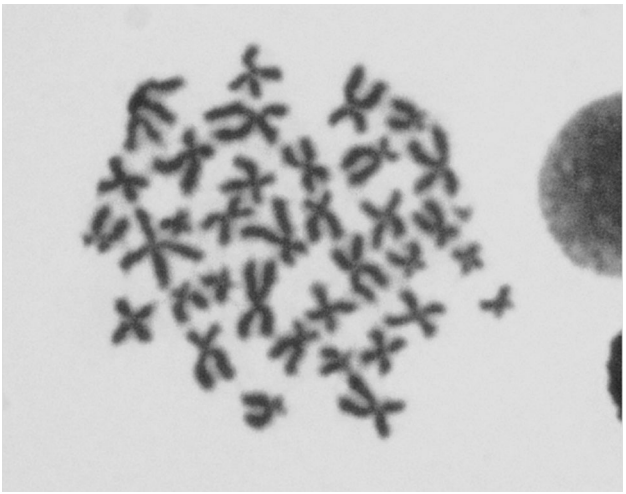

Fig. 1 Karyotype of bone marrow cells of *Citellus pygmaeus*, $2n = 36$, Gimsa, ×1,000

One of the major contributors to environmental pollution is the space industry, which has been rapidly growing in recent decades (Erickson et al. 1989; Hansard et al. 2011; Gamper-Rabindran and Finger 2013; Swart 2013). The operation of rocket and space systems may affect the environment through generation of noise, vibration, and contamination by highly toxic rocket fuel as a result of the fall of parts of launched rockets (Yarmishko et al. 1999; Chugunov et al. 2000; Byr'ka et al. 2010). The main cause of soil contamination by fuel components is aerogenic dissemination and ground spills at the places where rocket parts fall to earth. It has been revealed that the fall of the first rocket stage results in the introduction of propellant (from 0.3 up to 2 tons) into the environment. The places, where residual rocket parts fall, usually have an ellipsoidal shape with an area of several hundred thousand square kilometers. Other sources of environmental contamination by rocket fuel are emergency rocket launches, spills during refueling operations, and rocket transportation (Romanov and Romanova 2003).

Since the late fifties, some territories of Kazakhstan and Russia have been experiencing the impact of rocket and space activities, including Baikonur, Plesetsk and others (Villain 1996; Lipanov 2003; Shatalov 2003). The results of field studies conducted at these territories indicated the presence of a component of rocket fuel 'unsymmetrical dimethyl hydrazine' (1,1-Dimethylhydrazine; UDMH) and its oxidation products, including *N*-nitrosodimethylamine (NDMA). NDMA has been found out in the soil, water and plants in the concentrations exceeding maximum permissible dose (Kaplan and Kaplan 1985; Ismagliov et al. 2004; Yang and Liu 2006).

For many years the Ulytau District of Karaganda region has been the landing site for the first stages of rockets. As a result, the area has been contaminated by the components of rocket propellant, including heptyl and its derivatives such as UDMH (Batyrbekova et al. 2008). It must be noted that in the environment UDMH can either remain stable or it can be oxidized to nitrosodimethylamine (NDMA), which is a strong carcinogen by itself (Liteplo and Meek 2001). As a consequence, the health status of the domestic population has been affected.

Table 1 Distribution of 1,1-DMH at the point of fall of the part of rocket «Proton»

Depth of sample (cm)	C, mg/kg (field data, expedition 09.06.2003)	Soil moisture (%)	C, mg/kg (field data, expedition 14.08.2005)	C, mg/kg (calculated data)
0	122.00	12	52.00	94.1
8	112.00	14	48.80	84.5
20	2.50	14	4.52	9.8
40	0.53	14	0.87	0.18
50	0.22	14	0.53	0.18
68	0.16	14	0.01	0.18

The monitoring of the polluted areas near cosmodrome "Baikonur" conducted few years ago showed the regularity of distribution of highly toxic unsymmetrical dimethylhydrazine and its derivative products in the soils of Central Kazakhstan (Fig. 1).

The highest level of the soil pollution by propellants and their derivatives in Central Kazakhstan has been observed at the point of landing of the rocket's vehicle and fuel tank as a result of fuel spillage. It has been also revealed that the levels of 1,1-DMH and its derivatives reduced proportionally with the distance from the point of rocket fall. The high contamination by 1,1-DMH has been observed in the topsoil (0–40 cm height), which exceeds the maximal permissible level more than 1,000 times.

Another dangerous factor is the feasibility of leaking and migrating components of rocket fuel and its derivatives from polluted areas to uncontaminated soils. The speed and progress of spreading of toxic agents depends on many factors, including conditions of natural soil barriers. The transformation of chemical components of rocket fuel occurs most intensively in the first 2 years after exposing to the nature. Then the process gets stabilized, including the levels of 1,1-DMH. Even in the regions, which did not experience the space-rocket activity for long period (over 20 years), the level of contamination of soil by 1,1-DMH still remains high (0.41–6.8 mg/kg) (Table 1).

Moreover, the pollution at space-rocket test sites has been enhanced by specific local climatic conditions. From geographical point of view, the regions adjacent to the Baikonur cosmodrome belong to the desert and semi-desert

area types, and they are characterized by low annual rainfall and frequent winds. These areas are characterized by poor biodiversity and low biological productivity, which makes them extremely sensitive and vulnerable to anthropogenic pressure. Therefore, the study of the functional state of natural ecosystems exposed to human activities is extremely important (Ghaznavi 1999; Ellis 2000; Medina et al. 2007; Sun and Tian 2012). Such studies require a biological model in order to characterize the contamination effect caused by human's technological activity. In our case, we have chosen the rodents from polluted areas as a model of bio-indication. Among all the species of mammals, rodents have a special interest for biologists and environmentalists. This is due to large number of rodents found in nature, their broad representation of the different food chains of ecosystems, and the opportunity to extrapolate the results of eco-toxicological analysis of this group to human beings (Schroder et al. 2003; Sanchez-Chardi et al. 2009; Gaschak et al. 2011).

The purpose of this study was to investigate the chromosomal instability in rodents (*C. pygmaeus*; *M. musculus*) as a result of the pollution from Baikonur cosmodrome.

Materials and methods

The results of Russian and Kazakh expeditionary fieldworks conducted at the places of fall of space rocket residuals have indicated the presence of UDMH and its oxidative metabolite *N*-nitrosodimethylamine (NDMA) in the soil, water and plants in higher concentrations comparing to the maximum permissible level (Kasimov et al. 1996; Kenessov 2010). As it was aforementioned, for many years the Ulytau District of Karaganda Region has been used as the landing site for the first stages of rockets, leading to contamination of the territory by the components of propellant (Batyrbekova et al 2008). The presence of these pollutants might have toxic and genotoxic impact on living organisms, including the humans, since all substances circulate in the environment and can be transmitted through the food chain.

As it was noted above, the rodents are convenient objects for the environmental monitoring (Schroder et al. 2003). In Kazakhstan widespread rodent species are little ground squirrels and house mice (*C. pygmaeus* and *M. musculus*). These rodents live in large areas, including polluted areas.

The objects of the study were representatives of the common rodents *C. pygmaeus* and *M. musculus*, trapped in Ulytau District of Karaganda Region (an area affected by pollution from Baikonur cosmodrome), and the rodents captured in the area of the river Sarisu in Kyzyl-Orda region (zone of conventional control). The trapping sites were the peripheries of small settlements and farms near contaminated areas of Ulytau district and conventional control zone. All trapped animals were males. The rodents were humanely killed via deep anesthesia by using Nembutal sodium solution (pentobarbital sodium). The excised livers were weighed and placed into a chilled 0.05 M Tris–HCl buffer (pH 7) with 0.1 M KCl and 0.9 mM EDTA. Then the organs were triturated with a Potter homogenizer in a 0.05 M Tris–HCl buffer. After this, the extracts were centrifuged for 10 min at 1,000×*g* to obtain a 10 % homogenate. The contents of primary and secondary products of lipid hydroperoxide (LHP) and malondialdehyde (MDA) were determined.

For determination of LHP, the diene structures of LHPs were isolated from 10 % liver homogenate by using a mixture of heptane and isopropyl alcohol (ratio of 1:1). Then a solution of HCl (pH 2) was added. The heptane layer was collected and the absorbency was measured at a wavelength of 233 nm on spectrophotometer SF-46 (Milaform, Russia). The contents of the LHPs were calculated taking into account that the molar extinction coefficient is 2.2×10^{-5} cm/M × 1 per 1 g of liver (wet weight) and expressed as mMol/mg.

The MDA content was determined by reaction with thiobarbituric acid (Schmedes and Holmer 1989). 1 ml of 17 % trichloroacetic acid was added to 2 ml of 10 % liver homogenate, and then it was agitated for 10 min. Then 1 ml of 0.8 % thiobarbituric acid was added to the solution, after this it was heated in a steam bath for 10 min, cooled down and centrifuged at 4,000×*g* for 10 min in a centrifuge. The color intensity of the produced trimethine complex was detected by using a spectrophotometer SF-46 (Milaform, Russia) at a wavelength of 532 nm. The amount of MDA was calculated using the molar extinction coefficient equal to 1.56×10^{-5}/cm/M on 1 g liver wet weight and expressed as mMol/mg.

Cytological samples for metaphase analysis were prepared by exploiting standard methods (Preston et al. 1987). Prior to sacrificing, each rodent was weighed. The colchicine solution was injected intraperitoneally into the animals (0.04 % of 1 ml per 100 g of body weight). After 1.5–2 h the animals were sacrificed, and then the femurs were excised from the body. The epiphyses were cut. The bone marrow was washed using a syringe with a hypotonic solution of potassium chloride (0.56 %), and placed in a preheated (up to 37 °C) graduated centrifuge tube of 10 ml.

The washed bone marrow was homogenized. Tubes with the cell suspension were placed into water bath at a temperature of 37 °C for 8–12 min. Then the cell suspension was subjected to hypotonic treatment, and centrifuged for 5 min at 1,000 rpm/min. The supernatant was removed with a pipette, and the precipitate was fixed with methanol and glacial acetic acid (3:1), and then placed in the refrigerator for 20 min. The fixative was changed 2–3 times followed by an intermediate re-suspension and

centrifuging. For the final fixation the 1.5–2 ml of cooled fixative was added to the suspension.

The fixed cells were carefully re-suspended in a fixative, and 5–6 drops of the suspension was applied with a Pasteur pipette on a chilled wet slide from a height of 5–6 cm. The glass was passed through the flame of a spirit lamp to burn off the fixative. After this the glass was dried in a stream of warm air. The samples were labeled and left before the final drying for 2–3 days, then stained by using Giemsa azure-eosin dye (Merch, Germany).

Cytogenetic analysis was performed by using the metaphase method, where the overall frequency and spectrum of chromosomal aberrations were determined. Metaphase plates were analyzed and photographed under a light microscope Axioskop-40 (Zeiss, Germany). The metaphase plates were accepted for further analysis if they met the following criteria's:

- The metaphase plate should have a roughly round shape and intact chromosomes;
- All chromosomes must be well distributed and uniformly stained; their density should not differ by more than two times;
- All the elements of the plate have to be uniquely identified prior to the count;
- The plates with presence of random chromosomes were excluded from analysis;
- The plates with many overlapping chromosomes, particularly longitudinal, were excluded from analysis due to the possibility of exchange aberrations;
- Only cross-imposition of the long arm was allowed, whilst the longitudinal imposition of big and middle chromosomes was not accepted.

It must be noted that the loss of chromosomes in the metaphase plate is technically inevitable. In this regard, the analysis was allowed only for cells with a chromosome number not less than 40 and not more than 44, i.e. 42 ± 2 chromosomes.

Statistical analysis of the quantitative studies was carried out according to the standard procedure using Student's t test. To obtain an average of the value, statistical indicators were treated by exploiting the conventional methods of variation statistics.

Results and discussion

We have previously demonstrated in in-vivo studies that the toxicity of 1,1-DMH and NDMA contributes to an increase of lipid peroxidation and inhibition of antioxidant enzymes (Mahmoud et al. 2011, 2012). This oxidative stress has been mainly induced by NDMA, which conforms to other reports (Parks et al. 2001; De Felice et al. 2007). Apart from that, we have observed an enhancement of the mutation process in laboratory animals (Mahmoud et al. 2011, 2012; Carlsen et al. 2009).

The accumulation of MDA in the liver of animals from the contaminated areas occurred as a result of reduced activity of antioxidant enzymes, including catalase. It is known that the metabolism of 1,1-DMH and NDMA can lead to the formation of nitric oxide (NO), which binds to the active site of the enzyme therefore reducing its catalytic activity (Brunelli et al. 2001; Sigfrid et al. 2003). As a result of the fall of catalase activity, peroxide has been accumulated in the liver, which enhanced the process of lipid peroxidation.

Table 2 illustrates the results of the determination of biochemical products of lipid peroxidation. The content of LHP (primary product LHP) in the liver of *C. pygmaeus* and *M. musculus* was 1.7 and 1.9 times ($p < 0.01$) higher in comparison to the animals from the control group. The content of malondialdehyde (secondary PLO) in the liver of both species from the contaminated habitats were 1.6-fold ($p < 0.01$) higher in comparison to the animals from the control zone.

The concentrations of 1,1-DMH and NDMA in soil and plants were elevated in the native habitat areas of the rodents (*C. pygmaeus* and *M. musculus*). Such amounts of those agents can cause toxic and genotoxic effects in mammals. In this regard, we have investigated products of lipid peroxidation in liver and levels of chromosomal aberrations of *C. pygmaeus* and *M. musculus*, inhabiting the territories contaminated by rockets propellants.

These results indicate the amplification of free radical processes, which can be caused by the presence of toxic environmental factors, in particular by the components of rocket propellants (1,1-DMH and NDMA).

The results of cytogenetic analysis of bone marrow cells of rodents collected in the area of Ulytau showed increased frequency of metaphases with structural and genomic mutations compared to the rodents from the area of conditional control (Table 3).

The frequency of aberrant and polyploid cells, and the number of chromosome aberrations per 100 metaphases were 2.26, 0.74 % and 2.64 in animals from the control area, while the same indicators of the rodents from the polluted region increased up to 3.2 ($p < 0.001$), 3.3 ($p < 0.05$) and 3.5-fold ($p < 0.001$) respectively. Besides the aneuploid metaphases, the polyploid chromosomes were detected as well. The range of chromosomal aberrations was represented by structural rearrangements of chromosomal and chromatid type, including chromosomal pair terminal fragments. Figures 1 and 2 represent normal karyotype of male *C. pygmaeus* (diploid cell with 36 chromosomes) and chromosomal aberrations respectively. Amid chromosomal aberrations the single concentric rings

Table 2 Levels of LHP products and MDA in the liver of *Citellus pygmaeus* and *Mus musculus* inhabiting areas exposed to pollution from the Baikonur cosmodrome

Place of rodent trapping	Name of species	Amount of analyzed cells	Frequency of aberrant cells, (M ± m) (%)	Number of chromosoal aberrations on 100 metaphases			Frequency of polyploid cells, (M ± m) (%)
				Total aberrations	Chromosome type	Chromatid type	
Area of conditional control (near the river Sarisu of Kyzylorda region)	*Citellus pygmaeus* Pallas	1,050	2.26 ± 0.32	2.64 ± 0.32	0.64 ± 0.21	2.30 ± 0.25	0.74 ± 0.38
	Mus musculus L.	1,120	2.62 ± 0.36	3.00 ± 0.30	0.60 ± 0.17	2.40 ± 0.32	1.00 ± 0.39
Ulytau district of Karaganda region (zone exposed to pollution from Baikonur spaceport)	*Citellus pygmaeus* Pallas	1,250	7.28 ± 0.83**	9.66 ± 0.78**	1.90 ± 0.44*	7.76 ± 0.71**	2.45 ± 0.45*
	Mus musculus L.	1,310	5.81 ± 0.33**	7.98 ± 0.47**	2.13 ± 0.46*	5.85 ± 0.36**	2.54 ± 0.24*

* $P < 0.05$, ** $P < 0.001$ in comparison with values of control group

Table 3 Frequency spectrum and structural abnormalities of chromosomes of bone marrow cells of *Citellus pygmaeus* and *Mus musculus* from the habitats of Ulytau District of Karaganda Region

Place of rodent trapping	Name of species	Level of LHP (mMol/mg)	Level of MDA (mMol/mg)
Area of conditional control (near the river Sarisu of Kyzylorda region)	*Citellus pygmaeus*	2.11 ± 0.19	2.69 ± 0.30
	Mus musculus L	1.74 ± 0.19	2.29 ± 0.29
Ulytau district of Karaganda region (zone exposed to pollution from Baikonur Spaceport)	*Citellus pygmaeus*	3.50 ± 0.35**	4.39 ± 0.33**
	Mus musculus L	3.22 ± 0.30**	3.72 ± 0.35*

* $p < 0.05$, ** $p < 0.01$ comparing to control

Fig. 2 Chromosomal pair terminal fragments of bone marrow cells of *Citellus pygmaeus*. Gimsa, ×1,000

were observed along with paired terminal deletions. The aberrations of the chromatid type were presented by single terminal deletions, point fragments, and acentric rings. The significant increase of chromosomal rearrangements (3.0 times, $p < 0.05$) and chromatid (3.4 fold, $p < 0.001$) types was detected. In the spectrum of structural chromosome aberrations the chromatid-type aberrations prevailed ($p < 0.001$).

Cytogenetic analysis of bone marrow cells of the house mouse (*M. musculus* from the territory Ulytau District of Karaganda Region) showed elevated levels of cells with chromosome aberrations in comparison with the animals from 'clean' areas (Table 3). Figure 3 demonstrates normal karyotype of male *M. musculus* (diploid cell with 40 acrocentric chromosomes).

Thus, the frequency of aberrant and polyploid cells, and the number of chromosomal aberrations in 100 metaphases of *M. musculus* from the control zone were respectively 2.62, 1.00 and 3.00 %; whereas the same parameters of the mouse from contaminated areas were 2.6 ($p < 0.001$), 2.5 ($p < 0.05$) and 2.7-fold more ($p < 0.001$), respectively. Apart from polyploid metaphases (Fig. 4), the cells with the aneuploid set of chromosome were detected. The range of chromosomal aberrations was represented by all types with dominance of violations of chromatid type, including

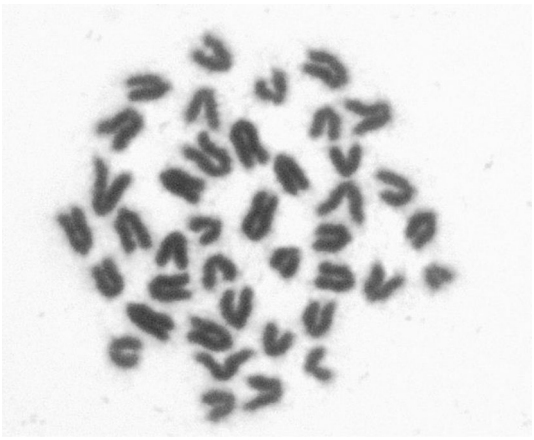

Fig. 3 Karyotype of bone marrow cells of *Mus musculus*, $2n = 40$, Gimsa, ×1,000

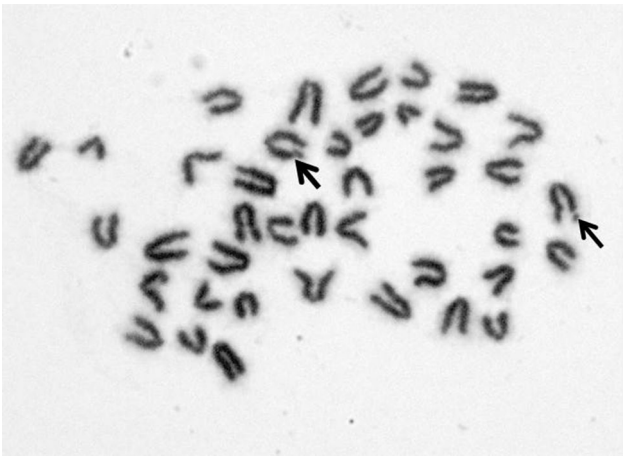

Fig. 5 Chromatid single terminal fragment and chromatid single terminal deletion of bone marrow cells of *Mus musculus* (*black arrows*). Gimsa, ×1,000

Fig. 4 Polyploid bone marrow cells of *Mus musculus*. Gimsa, ×1,000

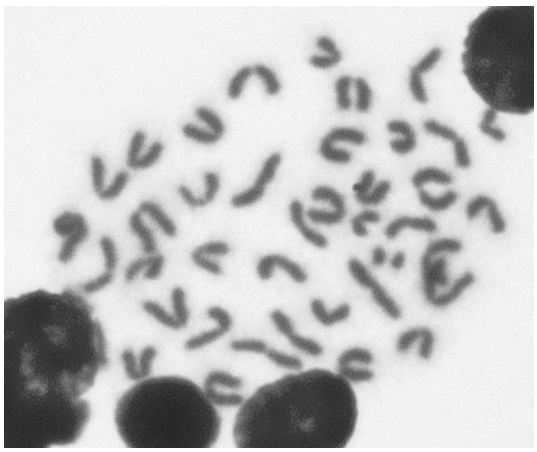

Fig. 6 Chromosomal pair terminal deletions of bone marrow cells of *Mus musculus*. Gimsa, ×1,000

chromatid single terminal fragmentation, chromatid single terminal deletion, and chromosomal pair terminal deletions (Figs. 5, 6). A significant increase in both chromosomal rearrangements (3.6-fold, $p < 0.05$) and chromatid (1.8 fold, $p < 0.001$) types was detected in *M. musculus* from the contaminated region. The level of polyploid metaphases in animals from areas affected by Baikonur cosmodrome was significantly higher compared to the control group. Among the samples with polyploid metaphase the cells with mainly tetraploid chromosome were detected.

As a result of cytogenetic studies the fact of chromosomal instability in representatives of *C. pygmaeus* and *M. musculus* species (from areas exposed to the rocket propellants) has been established. It indicates about the presence of genotoxic factors in their natural habitat. The detected high level of chromosomal abnormalities of the chromatid type indicates a significant chemical contamination of the environment. The results showed increasing mutation load in rodent populations from natural ecosystems affected by anthropogenic pressure. An acceleration of the frequency of mutations increases the number of individuals with congenital defects that, ultimately, constitutes a threat for the existence of the general population (Ayas et al. 2000; Beauchamp et al. 2007; Malaquias et al. 2009).

A significant increase of lipid peroxidation products in the rodents liver from contaminated habitats compared to the control area ($p < 0.05$, $p < 0.01$), indicates the presence of xenobiotics in the environment. The frequency of structural and genomic mutations in bone marrow cells of

the small ground squirrels and the house mice from Ulytau District of Karaganda Region was significantly higher ($p < 0.05$, $p < 0.01$) compared to the animals from the control area.

The genotoxic effect of UDMH and its oxidation product NDMA has been already demonstrated by authors of this article in experiments on laboratory animals. The spectrum and high level of chromosomal aberrations in animal models were similar to the genomic and structural abnormalities found in rodents from areas contaminated by heptyl and its derivatives, and to the results of control group too.

It must be noted that many harmful environmental factors can affect the genetic apparatus of the cell, resulting in damage of the genome, which may take the form of chromosomal aberrations (Seo 2012). The level of aberrations may indicate the degree of contamination of the environment; and it can play the role of a biomarker for mutagenic factors (Vargas 2003). One of the most promising approaches for the detection of mutagenic factors in the natural environment is the cytogenetic method. It has been demonstrated that even in optimal conditions for an organism, the various genetic aberrations can spontaneously arise (Yamaguchi 1975; Woodruff and Thompson 1982; Lebedeva et al. 1993; Sal'nikova 2012). When exposed to adverse environmental factors, the frequency of genetic defects may increase as a result of damage to the immune and DNA repairing systems, which can lead to a breach of cytogenetic homeostasis. As a result, there are individuals in a local biosphere with an increased frequency of chromosomal abnormalities. The study of such abnormalities allows an evaluation of the degree of environmental contamination by toxicants.

It has been shown that different pollutants and toxicants can induce lipid peroxidation associated with the activity of free radicals and the production of reactive oxygen species (ROS) in mammals (Goodman and Hochstein 1977; Dickens et al. 1988; Wardle 1990; Ferrari 2000). In turn, ROS may trigger the degradation of membranes, a reduction of activity of enzymes (such as enzymes of cytochrome P450 system) and hormones that can lead to DNA damage, impairment of cell cycles and, ultimately, initiate cell death (Takeuchi et al. 1996; Bennett 2001; Ogawa et al. 2003; Qi 2010). Previously some studies have already demonstrated that free radicals can damage DNA via single-and double-strand breaks, the formation of DNA–protein cross-links, and oxidative modification of nucleotide bases (Cole et al. 1979; Devi et al. 2000; Albino et al. 2006; Bryant 2012; Schipler and Iliakis 2013).

The most common type of DNA damage is single-strand break that, unlike double-strand breaks, can be almost completely repaired. This DNA damage can be triggered by products of lipid peroxidation. The amplification of lipid peroxidation is an irreversible oxidation of SH-groups of proteins, which can consequently lead to a violation of their functions and the entire chromatin in whole. Moreover, the activation of lipid peroxidation processes may induce the formation of cross-linking protein and protein covalently bonded polymers. The secondary products of lipid peroxidation such as MDA have crosslinking properties (Marnett 1999). It is well-known that the lipid free radicals (lipid peroxyl radicals) have an ability to form covalently linked protein polymers (Kikugawa et al. 1989), including DNA cross-linking, and other variations of cross-link covalent bonds between different amino acid residues of proteins, DNA bases and lipids (Noll et al. 2006). Such changes may result in a breach of transcription and translation, the occurrence of mutations, and the impairment of functional activity of proteins.

Currently the products of lipid peroxidation of chromatin are considered as one of the leading mechanisms of damaging of the nuclear genetic apparatus (Nair and Bartsch 2003; Almeida 2006; Negi et al. 2012; Winczura et al. 2012; Yardim-Akaydin et al. 2013).

Based on our findings we hypothesize that NDMA-induced lipid peroxidation of chromatin can lead to DNA damage. Moreover, UDMH and its oxidation products may adversely affect the cellular repair system, which in turn could contribute to formation of the stable mutations.

Conclusions

The presented study provides the information about the effect of pollution caused by rocket activity on native species found in the wild. The obtained data demonstrated the role of derivatives of rocket fuel in the induction of free radical cascades and the developing of lipid peroxidation. It consequently leads to DNA damage thus affecting the health of the inhabitants of polluted territories. The analysis of such processes can help to extend the understanding of toxic and mutagenic effects of 1,1-DMH and NDMA on living organisms.

During these studies we have demonstrated that chromosome instabilities could play a role of bio-indicators of the level of contamination of the environment by products of space-rocket activities. Based on these findings, one can estimate the genetic risk of this type of eco-toxicants. The gained knowledge about the morphogenetic and cytogenetic changes induced by components of rocket propellant and its derivatives will provide a foundation for developing recommendations regarding ecological regulations for local authorities.

To summarize, the biodiversity conservation of wildlife, as well as improving the health of the population can be addressed through the development and implementation of

environmental and health measures on the basis of knowledge about the sensitivity of organisms to the action of harmful environmental factors.

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Conflict of interest The authors disclose no conflict of interest.

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