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CYTOGENETIC EFFECTS OF RADIATION FROM CHERNOBYL NUCLEAR ACCIDENT ON HUMANS AND ANIMALS IN THE CONTAMINATED AREA OF BELARUS

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ABSTRACT

Cytogenetic monitoring of amphibian and rodent populations, and children from the radiocontaminated regions of the Republic of Belarus was conducted as a follow up to Chernobyl nuclear accident. A statistically significant increase in the levels of cytogenetic damage in bone marrow cells of amphibians and rodents and in peripheral blood lymphocytes of children was found. The presence of chromosome-type aberrations supports the conclusion that radiation is the causative agent. However, no direct relationship between the level of radionuclide contamination and the degree of the cytogenetic damage was found.

RESUMEN

En regiones radiocontaminadas de la República de Bielorrusia se practicó el monitoreo citogenético en poblaciones de anfibios y roedores así como en niños, después del accidente nuclear de Chernobyl. Se comprobó estadísticamente el incremento significativo de daño a nivel citogenético en células de la médula osea en anfibios y roedores, así como en linfocitos de la sangre periférica de los niños investigados. La presencia de aberraciones de tipo cromosómico apoya la conclusión de que la radiación es el agente que las causa. Sin embargo, no se encontró una relación directa entre el nivel de contaminación de radionúclidos en el área y el daño citogenético.

INTRODUCTION

The Chernobyl nuclear accident caused a unique radioecological exposure situation in the territory of Belarus. A determination of the associated genetic hazards and planning of activities for the reduction of the radiological risks cannot be accomplished using physical measurements only. The territory of the republic is heterogeneous not only in regard to contamination levels but also in the spectrum of radionuclides, each having a different genetic effect, in the biogeochemical features of various soils resulting in different coefficients of radionuclide transfer from soil to plants and in the extent of transfer through the food chains to people. Thus, an investigation of the level of chromosomal damage in organisms residing in the contaminated areas will provide a more realistic picture of the cytogenetic effects of contamination.

The objective of this study was to investigate the level of chromosomal damage in humans and animals in the contaminated areas and to analyse the relationships of the level of contamination on damage frequency and on the radionuclide accumulation in the organisms.

MATERIALS AND METHODS

Apart from humans, the bank vole (*Clethrionomys glareolus*) and brown frogs (*Rana temporaria L.* and *Rana arvalis Nils*) were chosen as investigation objects. Pubescent animals were used in the study. Chromosomal aberrations in human peripheral blood limphocytes (PBL) were measured by metaphase and micronucleus methods; chromosomal aberrations in bone marrow cells at the metaphase stage were analysed in amphibians and murine rodents. All aberrations of chromosome-and chromatid-type were registered. Gaps were not included into the number of aberrations. Coloration, the same as that of the nucleus, and sizes within 1/3 of the nucleus were a criterion to identificate the micronuclei. No special studies were conducted to reveal stable aberrations. Conventional methods (Ford and Hamerton 1956, Moorhead *et al.* 1960, Shmid 1978, Fenech and Morley 1985) were used for preparing cytogenetic specimens.

The contents of ^{137}Cs, ^{134}Cs, and ^{106}Ru in animal organisms were determined by gamma-spectrometry ADCAM-300 (ORTEC-USA). ^{90}Sr was determined by daughter ^{90}Y by a radiochemical method. The method is

based on mineralization (thermal and chemical ashing) of a biological sample, its conversion into soluble homogenous state, followed by ^{90}Y radiochemical purification of associate radionuclide impurities, ^{90}Y precipitations as oxalate on target and on radiometic determinations of its β-activity.

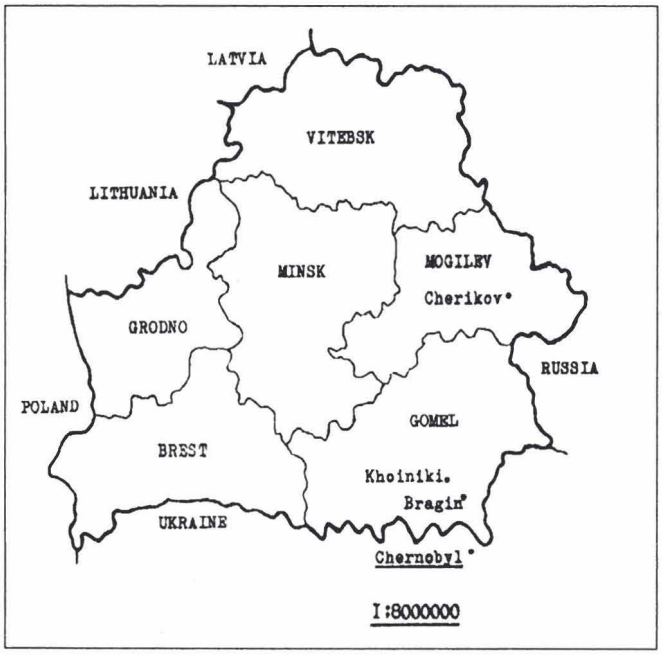

Fig. 1. Map of Belarus

Dose loads on animals and tissues were determined on the basis of general approaches with due account of object geometrical sizes (Osanova and Likhtarev 1977).

Samples from brown frog populations inhabiting the following sites were analysed:

1. The vicinity of the village of Babchin, Khoiniki District, Gomel Region (1110 kBq/sq m ^{137}Cs; 77.7 kBq/sq m ^{90}Sr).
2. The vicinity of the village of Lomachi, Khoiniki District, Gomel Region (2331 kBq/sq m ^{137}Cs; 284 kBq/sq m ^{90}Sr).
3. The vicinity of the village of Savichi, Bragin District, Gomel Region (740 kBq/sq m ^{137}Cs; 55.5 kBq /sq m ^{90}Sr).
4. The vicinity of the village of Strumen, Kormyany District, Gomel Region (1554 kBq/sq m ^{137}Cs; 44.4 kBq/sq m ^{90}Sr).
5. The vicinity of the town of Cherikov, Mogilev Region (177.6 kBq/sq m ^{137}Cs; 3.7 kBq/sq m ^{90}Sr).
6. The vicinity of the village of Verpin, Chericov District, Mogilev Region (1202.5 kBq/sq m ^{137}Cs; 10.0-55.5 kBq/sq m ^{90}Sr).
7. The Berezinsky Biosphere Reserve, Lepel District, Vitebsk Region (a control).
8. The coastal zone of the Zaslavl Reservoir near the village of Ratomka, Minsk District (a control area comparable with the districts of Gomel and Mogilev Regions in the level of economic activities).

Groups of childrens for cytogenetic examination were formed on the basis of administrative divisions within the territory.

1. The 30-km zone of Bragin District, Gomel Region (^{137}Cs from 129.0 to 815.0 kBq/sq m; ^{90}Sr from 103.6 to 170.2 kBq/sq m).
2. The town of Bragin, Gomel Region (712,0 kBq/sq m ^{137}Cs; 77.7 kBq/sq m ^{90}Sr).
3. The town of Khoiniki, Gomel Region (222.0 kBq/sq m ^{137}Cs; 25.5 kBq/sq m ^{90}Sr).
4. The village of Novoselki, Khoiniki District, Gomel Region (706.7 kBq/sq m ^{137}Cs; 72.2 kBq/sq m ^{90}Sr).
5. The village of Rudnoe, Khoiniki District, Gomel Region (518.0 kBq/sq m ^{137}Cs; 111.0 kBq/sq m ^{90}Sr).

Geographic interlocation of Chernobyl and the administrative regions, where investigation was carried out, is given in **figure 1**.

The radiation monitoring data of the radiocontaminated areas are given as of July 1, 1989 (USSR State Committee for Hydrometeorology 1989). The results of cytogenetic examination of children from Minsk and Braslav, Vitebsk Region, were used as a control populations. Selection of the children for examination was random. There were no virus diseases and x-ray examination in their medical histories. Significance of the differences was calculated by Student's-t test.

RESULTS

The frequencies of aberrant cells in bone marrow of amphibians sampled from the regions of study for the period of 1986 to 1992 are presented in **Fig. 2**. The frequency of bone marrow aberrant cells of animals inhabiting the contaminated areas of Gomel and Mogilev Regions were significantly higher than in animals from the Berezinsky Biosphere Reserve and the vicinity of the Zaslavl Reservoir ($0.001>P<0.05$).

The incidence of aberrant cells was not significantly different between 1986 and 1989 despite the fact that the level of background radiation was declining due to the presence of short-lived radionuclides. A tendency toward lower frequencies of chromosomal damage was present between 1990 and 1992 in Babchin, Cherikov and Savichi, but the difference was not statistically significant. It is important to note that the level of chromosomal damage in animals from the Berezinsky Biosphere Reserve remained at the same (spontaneous) level after the Chernobyl accident. Therefore, a generalized "historical" control was subsequently used for frog data comparison.

Table I provides part of the same data in tabular form, with the level of chromosomal aberrations presented for

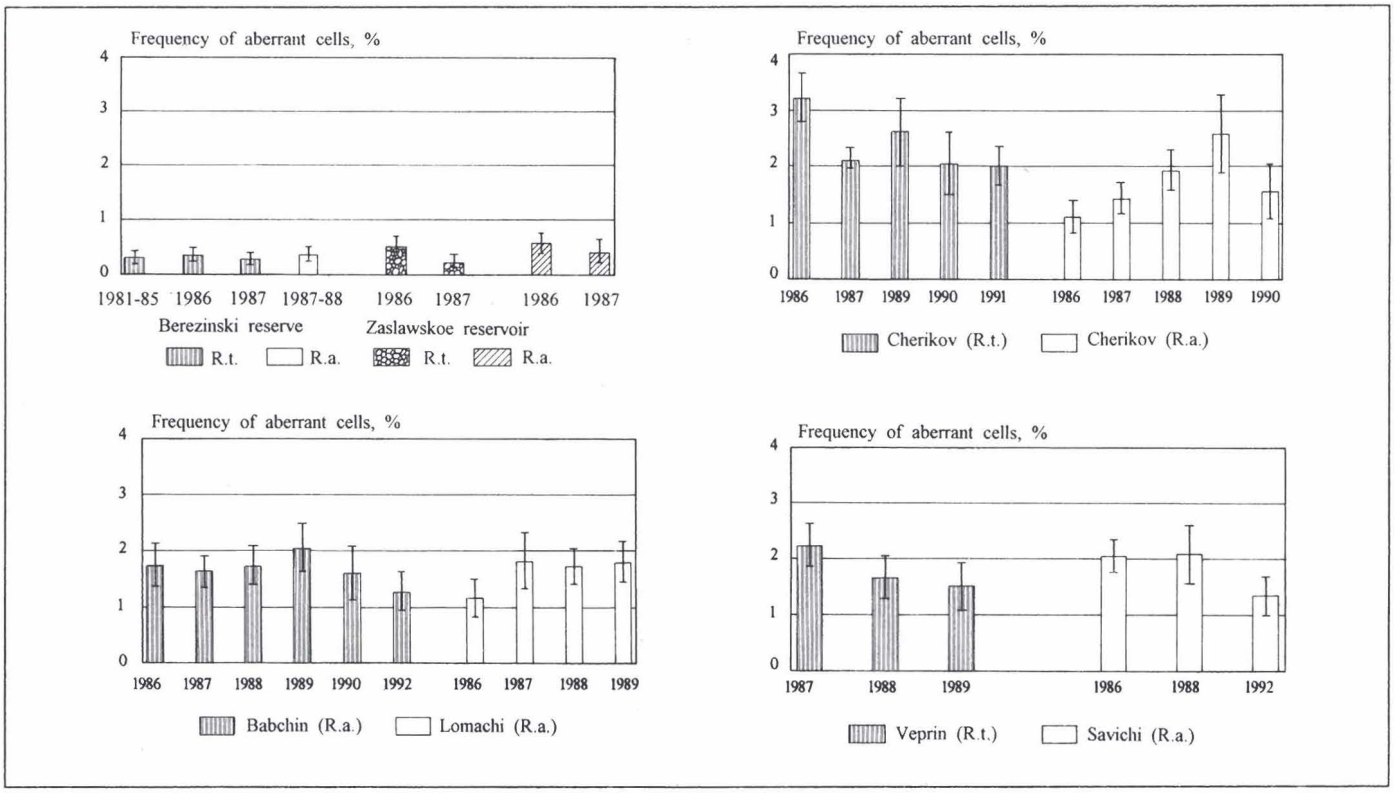

Fig. 2 Dynamics of aberrant metaphase frequency in (percentage with standard error bars) bone marrow cells of brown frogs

TABLE I. THE LEVEL OF CROMOSOME DAMAGE IN BONE MARROW CELLS OF BROWN FROGS FROM VARIOUS AREAS OF BELARUS (1986-1992)

Area	Period (years)	Animal	animals examined	No. of cell scored	No. of aberrant cells	No. of aberrations	No. of of aberrant cell (± SE)	Percentage of aberrations aberrant	Mean number per cell examined
Berezinski Biosphere Reserve	1986-1992	*R.t.*	70	6181	19	19	0.31 ± 0.007	1.00	0.003
		R.a.	19	1840	7	8	0.38 ± 0.14	1.14	0.004
Zaslavl Reservoir	1986-1992	*R.t.*	44	2838	14	14	0.49 ± 0.13	1.00	0.004
		R.a.	25	2151	13	13	0.60 ± 0.17	1.00	0.006
Savichi	1986-1989	*R.a.*	39	2621	54	59	2.06 ± 0.28	1.09	0.023
	1990-1992	*R.a.*	16	1057	14	15	1.33 ± 0.35	1.07	0.014
Babchin	1986-1989	*R.a.*	82	4917	86	102	1.75 ± 0.19	1.19	0.021
	1990-1992	R.a.	22	1702	24	25	1.41 ± 0.28	1.04	0.015
Chericov	1986-1989	*R.t.*	117	6149	173	225	2.81 ± 0.21	1.30	0.032
		R.a.	65	4837	77	82	1.59 ± 0.18	0.06	0.017
	1990-1992	*R.t.*	25	1439	29	32	2.02 ± 0.37	1.10	0.022
		R.a.	10	587	9	10	1.53 ± 0.50	1.11	0.017

R.t. = *Rana temporaria*
R.a. = *Rana arvalis*

TABLE II. SPECTRUM OF CHROMOSOME ABERRATIONS IN BROWN FROGS FROM VARIOUS AREAS OF BELARUS (1986-1992)

Area	Period (years)	Animal	No. of cells scored	No. of aberrations	chromosome-type aberrations, %			chromosome-type aberrations, %		
					total	exchanges	fragments	total	exchanges	fragments
Berezinski Biosphere Reserve	1981-1989	*R.t.*	6181	19	5.0	-	5.0	95.0	-	95.0
		R.a.	1840	8	-	-	-	100.0	-	100.0
Actue irradiation (2 Gy)		*R.t.*	547	81	64.2	23.5	40.7	35.8	13.6	22.2
Babchin	1986-1989	*R.a.*	4917	102	15.7	6.9	8.8	84.3	8.8	75.5
	1990-1992	*R.a.*	1702	25	24.0	8.0	16.0	76.0	-	76.0
Savichi	1986-1989	*R.a.*	2621	59	23.7	10.2	13.5	76.3	3.5	72.8
	1990-1992	*R.a.*	1057	15	6.7	-	6.7	93.3	-	93.3
Chericov	1986-1989	*R.t.*	6149	225	20.0	8.4	11.6	80.0	2.7	77.3
	1990-1992	*R.a.*	1439	32	28.1	6.3	21.8		-	71.9

R.t. = *Rana temporaria*
R.a. = *Rana arvalis*

animals from the same sites pooled for the years 1986 to 1992 (controls) or for 1986 to 1989 and 1990 to 1992 for the contaminated sites. The percentage of aberrant cells and the number of aberrations per cell detected in animals captured between 1986 and 1989 and 1990 and 1992 was significantly higher (3-9 times) than that in the control population. In addition, a lower percentage of aberrant cells was observed in *Rana arvalis* from Savichi and Babchin and *Rana temporaria* from Chericov in 1990 to 1992 as compared to the previous period. However, the difference was not statistically significant ($P>0.05$). Possibly, an analysis of larger numbers of animals and/or cells would demonstrate a reduction in the level of chromosomal aberrations in bone marrow cells of animals in recent years.

The increased average of aberrant cells in animals from the radiocontaminated regions cannot be ascribed to 1-2 animals with a very high number of aberrant cells. The variation coefficient reflecting variability among the animals by percentage of aberrant cells makes up 27-100% (from 50 to 150 metaphases were analyzed in each animal).

The aberration number in the damaged cells were higher as well as the percentage of cells with aberrations in the animals from contaminated areas. Only one cell with two fragments (the Berezinsky Biosphere Reserve, *R. arvalis*) was detected among 13010 control metaphases. This is the only case seen by us in the control group over the whole period of our investigations in amphibians and rodents. By counting this cells, the average number of aberrations per aberrant

TABLE III. RADIONUCLIDE CONTENT IN FROGS AND DOSE RATES FROM DIFFERENT SOURCES

Area	Animal	Content (Bq/kg)					Dosage rate (mSv/day)	
		^{90}Sr	^{106}Ru	^{137}Cs	^{134}Cs	from ^{90}Sr in bone tissue	from outer incorporated sources per whole body	from external irradiation per whole body
Savichi	*R.a.*	2345	*	442	115	0.170	0.021	0.059
Babchin	*R.a.*	1015	454	7272	1931	0.077	0.230	0.250
Lomachi	*R.a.*	595	41	2500	625	0.045	0.058	0.170
Strumen	*R.a.*	455	*	1463	487	0.035	0.070	0.180
Chericov	*R.a.*	66	116	5465	1534	0.005	0.100	0.013
	R.t.	129	*	1469	408	0.010	0.038	0.013
Verpin	*R.t.*	1050	*	5294	1568	0.080	0.150	0.130

R.t. = *Rana temporaria*
R.a. = *Rana arvalis*
* below method sensitivity

TABLE IV. RADIONUCLIDE ACCUMULATION LEVEL AND CHROMOSOME ABERRATIONS FREQUENCY IN BONE MARROW OF *Clethrionomys glareolus* FROM KHOINIKI DISTRICT OF GOMEL REGION

Variant examination	No. of animals examined	No. of cells scored	Percentage of aberrant cells (± SE)	Mean number of aberrations per cell	Radio nuclide content Bq/kg (mean ± SE) ^{90}Sr	^{137}Cs
After capture	29	2622	1.79 ± 0.26	0.019	75556 ± 1864	190.2 ± 27.2
One month feeding with radionuclide-free food	13	1956	1.07 ± 0.23	0.012	5653 ± 1173	155.4 ± 24.5
Control (Berenzinsky Biosphere Reserve)	25	2437	0.41 ± 0.12	0.004	< 2	< 10

cell in the control made up 1.02. For animals from the radiocontaminated regions the average was 1.23.

As it can be seen on **table II**, both chromatid- and chromosome-type aberrations were observed in animals from contaminated regions and in animals exposed to 2 Gy *X*-rays. Aberrations of chromosomal type are very rare in the control. Thus, among 13010 control metaphases (the Berezinsky Reserve and the Zaslavl reservoir) only one pair was revealed. With reference on the total number of aberrations (54), percentage of chromosome-type aberrations in the control made up only 0.5. There were exchange aberrations of chromatid- and chromosome-types in animals from radiocontaminated regions. Exchange aberrations were not found in the control. From the analysis of chromosome aberrations detected in animals in 1990-1992, it is impossible to make a definite conclusion about an essential change of the ratio of chromosomal to chromatid aberrations because of the relatively small total number of aberrations, though exchange aberrations were not found in four of six possible cases (chromatid exchange in animals from all the sites and chromosome exchanges in animals from Savichi).

The data of internal levels of radionuclides and the calculated dose rate in frogs are presented in **table III**. The data suggest a complex relatioship between exposure and dose equivalence which was site specific. Thus, for instance, in animals from Savichi, the largest contribution to the daily dose on bone tissue and, consequently on bone marrow was caused by the accumulation of ^{90}Sr; in Babchin, by other incorporated sources and external irradiation; in Lomachi, by external irradiation.

Since ^{90}Sr tends to accumulate in bones, separation of its contribution to the increased frequency of chromosomal aberrations in bone marrow cells was made by comparison of the level of cytogenetic damages and the radionuclide content in animals immediately after capture and after removal of much of the ^{137}Cs from the organism. In this experiment we used bank voles caught near Lomachi. For ^{137}Cs removal, the animals were fed with radionuclide-free food for 30 days which roughly corresponds to 10 periods of ^{137}Cs biological half-life (Kalistratova 1990). As can be seen from **table IV**, the population-average frequency of aberrant cells, obtained from animals fed with radionuclide-free food for a month, was 40% less than that in animals examined immediately after capture. However, the percentage of aberrant cells was still higher than that in the control ($P<0.02$). Spectrometric analysis revealed a 25 times lower ^{137}Cs content after a month. Therefore, the contribution of ^{137}Cs to the frequency of chromosome aberrations can practically be excluded for the group of animals fed with radionuclide-free food. Thus, the increased frequency of chromosome aberrations in these animals was brought about by incorporated ^{90}Sr, the amount of which was insignificantly reduced ($P>0.05$). This comparison suggests that about 50% of the chromosomal aberrations detected in the bone marrow cells of the voles collected from the Khoiniki district immediately after capture was induced by ^{90}Sr incorporated

TABLE V. THE LEVEL OF CYTOGENETIC DAMAGES IN PBL OF CHILDREN FROM THE 30-km ZONE OF BRAGIN DISTRICT AND BRAGIN ITSELF EXAMINED IN 1986

Settlement	No. of children examined	No. of cells scored	No. of cells with aberrations (mean per 10x2 cells ± SE)	No. of per cell
30-kg zone (10 villages)	60	18000	6.8 ± 0.2	0.0095
Bragin	15	3900	7.7 ± 0.4	0.0053
Control	18	3000	1.4 ± 0.2	0.0006

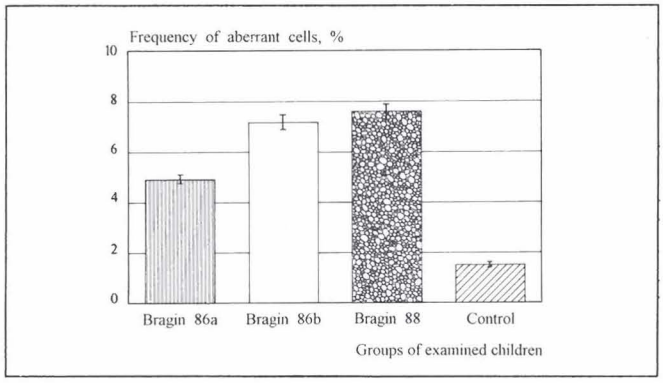

Fig. 3. Frequency of aberrant cells, percentage with standards error bars) in lymphocytes of children from bragin

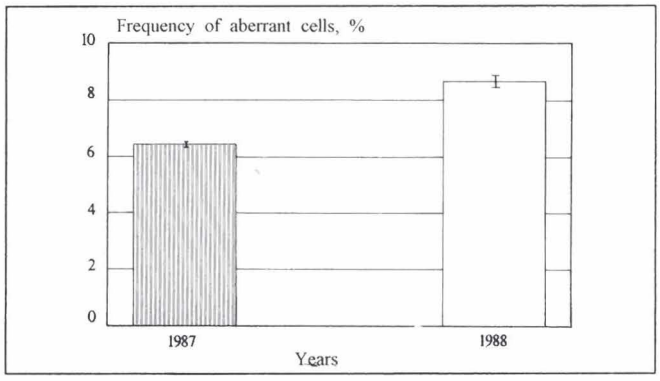

Fig. 5. Dynamics of aberrant cell level in lymphocytes of children from Bragin and Khoiniki Districts of Gomel Region

in bones, despite the fact that the level of ^{137}Cs contamination of the area was 8 times higher and the accumulation level on the organisms was, on the average, 380 times higher than that for ^{90}Sr.

The frequency of chromosome aberrations in peripheral blood lymphocytes of people who live in particular

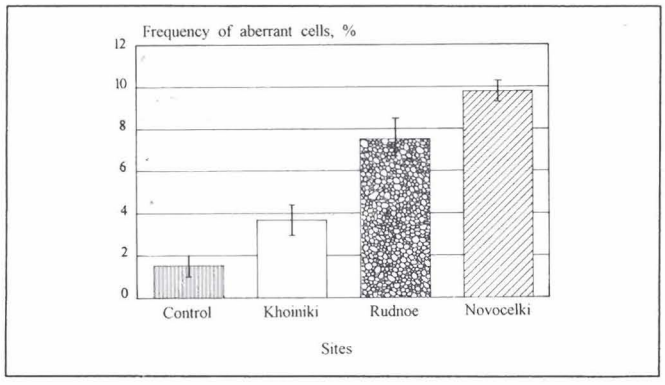

Fig. 4. Frequency of cytogenetic damages (percentage with standard error bars) in limphocytes of children from Khoiniki District

radioecological conditions are at present the most objective biological indicator of the radiation effect. Therefore, we examined the frequency of chromosomal damage in children from 10 villages within the 30-km zone of Bragin District, Gomel Region, who had been exposed for a short-time (2 weeks) to radiation, mainly due to fallout of short-lived radionuclides, and in children from Bragin exposed to additional subsequent radiation due to long-lived radionuclides.

Table V presents the group-average chromosome aberration yield for 60 children from 10 villages in 30-km zone of Bragin District. The children were evacuated on May 7-8, 1986 to a "clean" zone in Minsk Region (two weeks after the Chernobyl nuclear accident). Cytogenetic examinations were conducted in August, 1986. A statistically significant increase of the level of aberrant metaphases, aberrations per 100 cells, including markers of radiation effect, namely, dicentrics and centric rings, was observed for all the groups examined. Thus, the level of chromosome-type exchanges in the spectrum of chromosome aberrations in children lymphocytes varied in different villages from 0.0065 per cell to 0.0133. The population average number of dicentrics/rings per cell in children within the evacuation zone was 0.0095, as compared to the 0.0006 in the control.

Figure 3 shows dynamics of the clastogenic process in lymphocyte culture of children from Bragin. It should be noted that in most cases the same children were not examined at the different sample times. The level of aberrant metaphases in children evacuated a month after the catastrophe, was three times that in the control. The first examination of the children was conducted 3 months after being moved to an environmentally clean district in Minsk Region (Aug. 26, 1986). A repeated examination, carried out several months after the children had returned to Bragin (Dec. 5, 1986), showed a statistically significant increase in the yield of chromosomal aberrations compared to that in the first examination. It is important to note that the increase

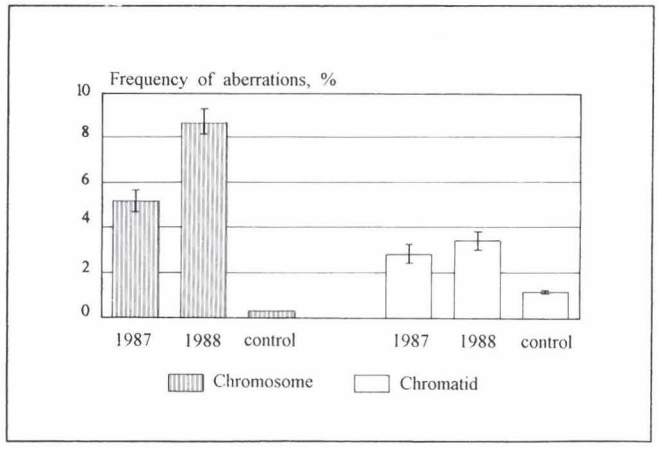

Fig. 6. Levels of different types of aberrations in periferal blood lymphocytes of the same children from Bragin and Khoiniki Districts, Gomel Region

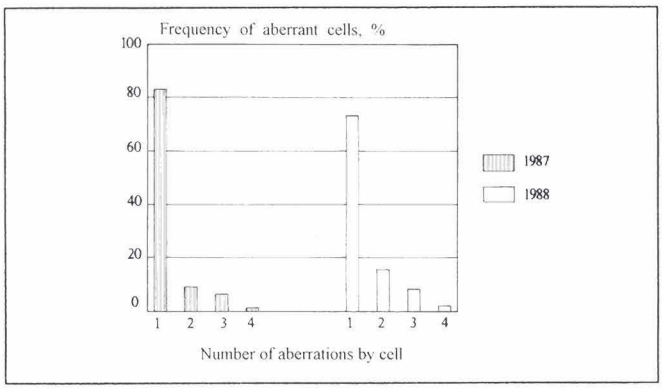

Fig. 7. The distribution of aberrant cells based on the number of aberrations in PBL on the same children from Bragin and Khoiniki Districts, Gomel Region

in the aberrant cell frequency above the control level was caused by an increase in chromosome-type aberrations. Thus, the radioecological situation in Bragin resulted in a substantial rise of the aberration level in lymphocytes of children after their return to the radiocontaminated territory. The cytogenetic effect specific for radiation was also present in children from Bragin examined in 1988 (**Fig. 3**) who had the aberrant cell frequency approximately at the level recorded during the second examination (Dec. 5, 1986).

A similar picture was observed in a group of children from Bragin, examined in 1991 by using the cytokinetic block method for micronucleus evaluation (Fenech and Morley 1985). The results confirmed the fact that an increased level of chromosomal aberrations remained in lymphocytes of the children. The number of detected binuclear cells with micronuclei was 5.3 times higher than the number found in the control population. Thus, the micronucleus test to cytogenetically examine children may, in some situations, be used as an equivalent of chromosomal aberrations analysis.

In the spring of 1987 a clinical and cytogenetic examination of 26 children, age 1-6 years, residing permanently in the settlement of Khoiniki and in the villages of Novoselki and Rudnoe, Khoiniki District, Gomel Region, was carried out. The data obtained indicated an increased level of chromosome aberrations in cultures of peripheral blood lymphocytes of these children: 3.7 ± 0.7, 7.6 ± 1.0 and 9.8 ± 0.5 % of aberrant metaphases, respectively, as compared to 1.5 ± 0.5 % in the control (**Fig. 4**).

In the spring of 1987 and 1988, a cytogenetic examination of the same children from Bragin and Khoiniki Districts was conducted to evaluate the dynamics of chromosomal aberrations. The first examination was carried out 12 months after the Chernobyl nuclear accident while the second examination was carried out 12 months later. The group-average data showed a significant increase in the total number of aberrant cells (**Fig. 5**) and in the number of chromosome-type aberrations (**Fig. 6**). The increase from 5.2 ± 0.5 % of chromosome type aberrations in 1987 to 8.7 ± 0.6 % in 1988 ($P<0.001$), was observed. A significant increase in the cell number with 2-4 aberrations (from 16.4 ± 3.3 % in 1987 to 27.0 ± 3.4 % in 1988 ($P<0.01$), was observed in the same children. Cells with 2 and more aberrations were not found in the control (**Fig. 7**).

DISCUSSION

These results demonstrate that the level of cytogenetic damage in human and animal cells was higher in all the radiocontaminated regions.

It is known that the types of spontaneous, chemically induced, and radiation-induced aberrations generally differ (Leonard 1986). The presence of chromosome-type aberrations supports a conclusion that radiation is the causative agent.

Apart from chromatid- type aberrations, radiation markers namely, dicentric and ring chromosomes, were found in the examined children groups.

Bone marrow cells proliferate continuously. Therefore, during exposure they occur at different stages of the cell cycle. In view of this, aberrations of both chromosome- and chromatid-types arise naturally which corresponds to irradiation at G_1 and G_2. The majority of chemical mutagens are S-dependent and induce aberrations of the chromatid-type only. As it is shown in **table II**, aberrations of the chromosome-type, including exchanges, were found in animals from contaminated regions in contrast to the control.

Multiple aberrations were found in cells of all the species studied. It is established that the distribution of aberrations tends toward overdispersion as the dose of any mutagen increases (Bochkov 1971, Goetz *et al.* 1975) or under irradiation with high linear energy transfer (LET) radiation (Sevankaev *et al.* 1976). Nonuniformity of irradiation can also contribute to this process.

Under uniform irradiation the aberration distribution in cells is of the Poisson type (Lea 1946). Comparison of the experimental and theoretical distributions has shown that in all the animal populations studied, except the *Rana temporaria* population from Cherikov (1986-1989), the experimental distribution agrees with the theory. X^2 is 11.3 for the Cherikov *Rana temporaria* population, at df=1 P=0.0042. For the other populations X^2 is in the range of 0.20 - 1.90, which indicates uniformity of irradiation.

The more frequent ocurrence of cells with 3 or 4 aberrations with increase of the time of stay of children in the radiocontaminated areas of Khoiniki and Bragin Districts seems to be associated with the time, change of the dose structure due to increase of the internal component contribution to the total radiation dose.

According to available data, the ^{137}Cs and ^{134}Cs contents in the examined children from Khoiniki and Bragin Districts, Gomel Region, in 1987-1988 varied between 0.18 and 9.14

mCi (the data were obtained by a human impulse counter). However, no correlation between the total gamma-activity and the yield of chromosome aberrations was revealed. In this connection, the results on reduction of the dose rate from external (Kazakov *et al.* 1991, Matyukhin 1992) and incorporated (Matyukhin 1990) gamma-sources on one hand, and on increase of accumulation on the other hand, deserve attention.

Because of poor radiation monitoring in the first months after the Chernobyl accident, biological dosimetry has become more and more important. Biodosimetry carried out on the basis of our findings by using different standard curves (Sevankaev and Nasonov 1978, IAEA 1986, de Campos *et al.* 1990) for evaluation of the absorbed dose has shown that the recorded level of chromosomal aberrations in children from the 30-km zone of Bragin District and the town of Bragin corresponds to the dose of 200-300 mSv.

According to the data of the Institute of Radiobiological Medicine (Belarus) based on the methods of physical dosimetry, the radiation doses received by the residents of those districts for 1986 to 1988 did not exceed 155 mSv. The reasons of the discrepancies require further investigation.

Unfortunalety, complete information about the radiocontamination level of all settlements at the moment of the analysis, is not available, which makes it difficult to investigate the correlation between the chromosomal aberration yield in children's lymphocytes culture and the contamination level of the area.

We have conducted a correlation of this type earlier for *Rana arvalis* (Yeliseeva *et al.* 1990) using the results obtained for 1986-1989. However, no correlation was found between ^{137}Cs and ^{90}Sr contamination of the environment and the chromosomal aberration yield. A trend of positive correlation ($r = 0.6 - 0.7$) was only found when analysing the correlation between ^{90}Sr accumulation in *Rana arvalis* and the cytogenetic damage yield. This correlation reflects the tropism of ^{90}Sr that accumulates in bone tissue and can make a great contribution to the aberration yield in bone marrow cells. There is no correlation between the chromosome aberration yield and ^{137}Cs accumulation. However, it should be taken into account that the coefficients considered are valid only for those particular places. With different radionuclide ratios in other regions, their relative contribution to the mutagenic effect can be different. From our point of view, the present data indicate that in some regions in Belarus, ^{90}Sr can induce substantial cytogenetic damages in bone marrow cells. This is confirmed by results obtained for murine rodents fed with radionuclide-free food to remove cesium (**Table IV**).

In general, as can be seen on **table III**, there is no direct relationship of the chromosomal aberration yield in bone marrow cells of frogs with the radiation dose received by bone tissue as the sum from external and internal irradiation. The differences in doses received by animals in different regions considerably exceed the difference in the frequencies of chromosome aberrations. It cannot be excluded that the effect observed can be attributed to an abnormal organisms response to low-dose radiation postulated by Luchnik (1957). A certain contribution can be made by modifying the effect of various ecological factors.

REFERENCES

Bochkov N.P. (1971). Human chromosome and radiation. Moscow, Atomizdat, 152 p.

de Campos I.M.A., dos Santos O.R. and Mesquita C.H. (1990). Dose estimation by cytogenetic analysis in a radiation accident with ^{137}Cs in Goiania (Brazil): evaluation of probable exposure doses range. Radiat. Protect Dos. *30*, 33-36.

Fenech M. and Morley A.A. (1985). Measurement of micronuclei in lymphocytes. Mutat. Res. *147*, 29-36.

Ford C.E. and Hamerton J.L. (1956). A colchicine citrate squash sequence for mammalian chromosomes. Stain Technol. *31*, 47-251.

Goetz P,., Sram R.J. and Dohnalova J. (1975). Relationship between experimental results in mammals and man. I. Cytogenetic analysis of bone marrow injury induced by a single dose of cyclophosphamide. Mutat. Res. *31*, 247-254.

IAEA (International Atomic Energy Agency) (1986). Biological dosimetry: chromosomal aberrations analysis for dose assessment. IAEA, Vienna.

Kalistratova V.S. (1990). Radioactive isotopes of the second group of the periodic system. In: *Harmful chemical substances. Radioactive substances.* Moscow, Atomizdat, pp. 77-117.

Kazakov V.S., Matyukhin V.A., Kenigsberg Ya. Z., Minenko V.F., Ispenkov E.A. and Moshchik K.V.(1991). Radioecological situation in Belarus after the Chernobyl accident, medicobiological consequences and scientific basis of measures for radiological protection of people. In: *Scientific and practical aspects of health safety of people exposure to radiation as a result of the Chernobyl accident.* BSSR, Ministry of Health, Minsk, pp. 3-6.

Khokhryakov V.F., Suslova K.K. and Skryabin A.M. (1992). Content of Pu isotopes in organism of residents in Gomel Region. In: *Scientific and practical aspects of health safety of people exposed to radiation as a result of the Chernobyl accident.* BSSR, Ministry of Health, Gomel, pp. 10-11.

Lea D.E. (1946). *Action of radiations on the living cells.* Cambridge University, London.

Leonard A. (1986). Dependence of cytogenetic effect on the dose of radiation and chemical mutagenic influence on *in vivo* somatic cells: the influence of exposure duration and cell selection. Tsitologia i Genetika *20*, 115-121.

Loseva L.P. (1991). Estimation of ^{90}Sr content in human organism. In: *Scientific and practical aspects of health safety of people exposed to radiation as a result of the Chernobyl accident*. BSSR, Ministry of Health Minsk, pp. 16-17.

Luchnik N.V. (1957). On abnormal responses at low radiation doses. Biophizika *2*, 52-57.

Matyukhin V.A. (1990). Radiation and ecological situation and medicobiological aspects of the aftermath of the Chernobyl accident in Belarus. Zh. Zdravookhranenie Belarusi 8-11.

Matyukhin V.A. (1992). Problems of the Chernobyl accident. Proc. Intern. Symp. on Chernobyl Catastrophe, Minsk, pp. 6-9.

Moorhead P.C., Nowell P.C., Mellman W.J., Battips D.M. and Hungerford D.A. (1960). Chromosome preparations of leukocytes cultured from human peripheral blood. Exp. Cell Res. *20*, 613-618.

Osanov D.P. and Likhtarev I.A. (1977). Dosimetry of incorporated radioactive substance radiation. Moskow, Atomizdat, 120 p.

Sevankaev A.V., Zherbin E.A., Luchnik N.V. and Obaturov G.M. (1976). Relative efficiency of fast and intermediate neutrons in induction of chromosome aberrations in human lymphocytes. Dokl. AN SSSR *227*, 975-977.

Sevankaev A.V. and Nasonov A.P. (1978). Standard dose curves of chromosome aberrations in human lymphocytes. Meditsinskaya Radiologia *23*, 26-33.

Shmid W. (1978). Chromosome banding in Amphibia. II. Constitutive heterochromatin and nucleus organizer regions in Ranidae, Microhylidae and Rhocophoridae. Chromosoma *68*, 131-148.

USSR State Committee for Hydrometeorology (1989). The data on ^{137}Cs and ^{90}Sr radioactive contamination of Belarus settlements (as of June 1989), Minsk, Polymya, 176 p.

Yeliseeva K.G., Voitovich A.M., Ploskaya M.V., Smal S.E. and Sokolik G.A. (1990). Genetic monitoring of Amphibia populations in Belarus regions with different levels of radiocontamination. Proc. 1st. Workshop Minsk, December 26-27, 1989, Minsk, pp. 232-239.