EVALUATION OF RADIATION EXPOSURE ON THE POPULATION, DOLON REGION SEMIPALATINSK TEST SITE, PHYSICAL AND BIOLOGICAL DOSIMETRY METHODS TAKING INTO ACCOUNT THE INDIVIDUAL RADIOSENSITIVITY

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Abstract

Comprehensive evaluation of dose loads on the population with physical methods of dosimetry, shows that expected annual effective dose from artificial radionuclides in Dolon is 0.07mSv/y of natural radionuclides 2.3 mSv/y. Cytogenetic examination of the inhabitants of Dolon village showed that the frequency of chromosomal abnormalities (2.7±0.19%) is significantly higher than in people from the control group (0.87±0.1%)($p \leq 0.01$). Radiosensitivity was assessed by the degree of increase in chromosomal aberrations of residents after in vitro exposure to 1Gy of γ-radiation in comparison with similar data of the control group. In people with an average radiosensitivity, a significant correlation (+0.70) is observed between the dose values determined by the methods of physical and biological dosimetry. Without taking radiosensitivity into account, the absorbed dose of irradiation in the examined varies from 0-0.3Sv(Gy). Taking into account the degree of radiosensitivity of individuals indicates that the average absorbed radiation dose of residents in Dolon is 0.11(Gy).

Key words: *chromosome aberrations, radiosensitivity, ionizing radiation, biodosimetry*

INTRODUCTION

The issues of controlling the intake of radioactive substances in the human body and their content in the body were and remain the most significant in the problem of radiation protection. This is due to the fact that radioactive substances are able to accumulate in the body, to be redistributed in tissues, reaching levels in certain organs that may be unsafe for health. One of the most important tasks in determining dose loads from the intake of radionuclides into the body is the accuracy of estimating the radionuclide content in the body by direct and indirect methods.

Evaluation of the genetic effects of ionizing radiation in humans is usually carried out with the help of biological dosimetry, which is carried out by analyzing chromosomal aberrations both unstable (routine method) and stable (methods of chromosome differential staining). The main method of biodosimetry is the analysis of cytogenetic lesions in cultured human cells.

When irradiating cells of the same donor *in vitro*, a strict dependence of the frequency of aberrations to the dose of radiation is observed. This gave grounds for using this criterion for the purpose of biodosimetry. However, the *in vivo* studies were found to be different from those of *in vitro*, and the results of biodosimetry often do not coincide with the doses documented by the dosimeters. At the same time, radiobiologists tend to believe that information obtained by biological methods is more reliable, and they conclude that the dose loads are incorrectly calculated, forgetting about the genetic differences of individuals. It is known that individuals of not only the same species, but even of the same population, can significantly differ in the degree of radiosensitivity. Most of the individuals are characterized by intermediate values of the trait, and only a small part of them have extreme values. The correct choice of adequate methods and criteria for estimating radiosensitivity is very important. Determination of the proportion of cells with chromosomal abnormalities is often used as a reliable quantitative indicator of radiosensitivity. On the one hand, the number of such damaged cells clearly depends on the dose of ionizing radiation, and on the other - reflecting its lethal effect, this criterion correlates well with the number of dead cells estimated by the decrease in the ability to clone formation. Also molecular-biological methods of quantitative evaluation of DNA damage, used in studying the mechanisms of radiation damage to cells and restore their viability, have been developed. The latter is due to the phenomenon of DNA repair, carried out by a special system of enzymes. The

effectiveness of DNA repair, according to modern ideas, is of decisive importance in cellular radiosensitivity.

The results of radiation effects at the organism level are affected by a huge number of factors, including the state of biochemical and physiological systems, the presence of hereditary diseases, etc. A number of substances can accelerate or slow the cell cycle, promote the transition of cells into the second or even the third mitosis. At the same time, the frequency of aberrations decreases several times, which sharply distorts the results of biodosimetry. With chronic irradiation, such population processes as, for example, elimination of lesions during physiological renewal of cellular composition are added, cells with disabilities predominantly eliminated. At the same time, multidirectional processes can occur in populations. On the one hand, adaptation takes place - the selection and multiplication of cells with a more resistant genotype, which leads to a decrease in the radiosensitivity of the population. On the other hand, there may be genetic instability, leading to an increase in the frequency of genetic disorders in the following generations. Thus, even with the use of special calibration curves, we cannot be save from serious errors in determining individual dose loads. In addition, the formation of nonspecific resistance of populations is a general pattern, manifested with long-term effects of a wide variety of environmental and anthropogenic factors. This phenomenon must be taken into account when assessing the genetic effects of environmental pollution.

When assessing the average and collective doses received by populations exposed to radiation (for example, the population living on radionuclide-contaminated territories), it can be assumed that the influence of all these factors is averaged, so the use of existing methods of biodosimetry in this case may be completely correct. However, when determining individual doses by these methods, significant errors may arise, which dictates the need to develop better methods for assessing the genetic effects of ionizing radiation in humans, taking into account its individual characteristics, as well as carrying out complex studies taking into account genetic, physical and radiochemical methods of dosimetry.

Therefore, for individual assessment of the dose load on the human body with chronic exposure to low-intensity γ-radiation, the task of establishing quantitative characteristics of the degree of radiosensitivity, adaptation and functioning of the reparative system becomes important. That can significantly reduce uncertainty in determining the effect of radiation doses and will allow taking into account their complex influence on the frequency of induced cytogenetic disorders (Thompson 2012) and the use of new technologies (Fenech 2011).

MATERIAL AND METHODS

Samples of peripheral blood for cytogenetic studies were taken from 74 people - residents of the village of Dolon (Semipalatinsk region, Kazakhstan) (mean age 39.5). As a control group, residents of ecologically pure Taukaraturyk village of Almaty oblast (45 people) (mean age 39.9) were used.

The definition of the radioecological state of the environment in Dolon and the assessment of doses by physical dosimetry methods were carried out by the Institute of Radiation Safety and Ecology of the NNC RK (Kurchatov, Kazakhstan), the results of which were kindly provided to us in the framework of joint research.

Preparation of metaphase chromosomes carried out by a standard technique (Moorhead et al. 1960). In the cytogenetic analysis of metaphase plates defined number of cages with aberrations, and also number and type of aberrations on 100 analyzed metaphases. From each individual analyzed from 200 to 400 metaphase cages. The obtained data processed statistical methods (Rokitsky 1978).

Radiation treatment (γ-radiation). To study the radiosensitivity of 74 inhabitants from Dolon, samples of their whole blood in plastic bottles were irradiated with γ-quanta at a dose of 1 Gy on a remote radiation therapy device with a cobalt charge "Theragam" with a nominal energy of accelerated electrons of 1.5 meV with a dose rate of 0.1 Gy / Min.

RESULTS

Assessment of dose loads on the population of Dolon using physical methods of dosimetry

The complex physical examination of dosimetry included - the investigation of the surface distribution of radionuclides, the assessment of the content of artificial radionuclides in the air, the assessment of the content of natural and artificial radionuclides in water for drinking and for economic purposes, the assessment of the content of natural and artificial radionuclides in food products of plant and animal origin. Based on these studies, an assessment of the dose loads on the population of the inhabitants of the Dolon settlement was carried out.

The main contribution to the dose of internal irradiation from inhalation intake of artificial radionuclides is made by radionuclide $Pu^{239+240}$ (~ 87%), natural radionuclides radon isotopes (~ 95%). The main contribution to the dose of external gamma radiation from artificial radionuclides is made by radionuclide Cs^{137} (~ 100%).

In the course of the estimated assessment of the dose loads on the population in Dolon, the following results were obtained: 1. The main contribution to the dose load on the population (with average values of the specific activity of artificial radionuclides in the surface layer of the soil) is the dose of internal irradiation from food products grown and produced in the study area. 2. The main contribution to the dose from external irradiation by artificial radionuclides is made by ^{137}Cs. The contribution to the dose of internal irradiation from the inhalation intake of radionuclides is $^{239+240}Pu$. 3. The main dose-forming radionuclide in food is ^{90}Sr.

In the course of the estimated assessment of the dose loads on the population, living and doing business in Dolon, the following results were obtained: The expected annual effective dose from artificial radionuclides in Dolon is 0.07 mSv/y. The results of the expected annual effective dose from artificial radionuclides will not exceed 0.3 mSv and is below the intervention level, according to the Hygienic Norms "Sanitary and Epidemiological Requirements for Radiation Safety" (Hygienic standards "Sanitary and epidemiological requirements for ensuring radiation safety 2012).

The expected annual effective dose from natural radionuclides may amount to 2.3 mSv / y in Dolon. The main contribution to the dose from natural radionuclides is the dose of internal irradiation from the intake of radon isotopes.

Cytogenetic analysis of people living in Dolon

The problem of studying individual biological reactions of the organism under radiation effects, searching for the most biological changes characteristic of these influences, takes one of the key places in modern radiobiology (Stepanenko et al. 2011).

Cytogenetic methods were used to examine people living in the Dolon settlement (the region of influence of the Semipalatinsk test site, Kazakhstan) (Table1).

Table 1. Cytogenetic examination of the inhabitants of Dolon

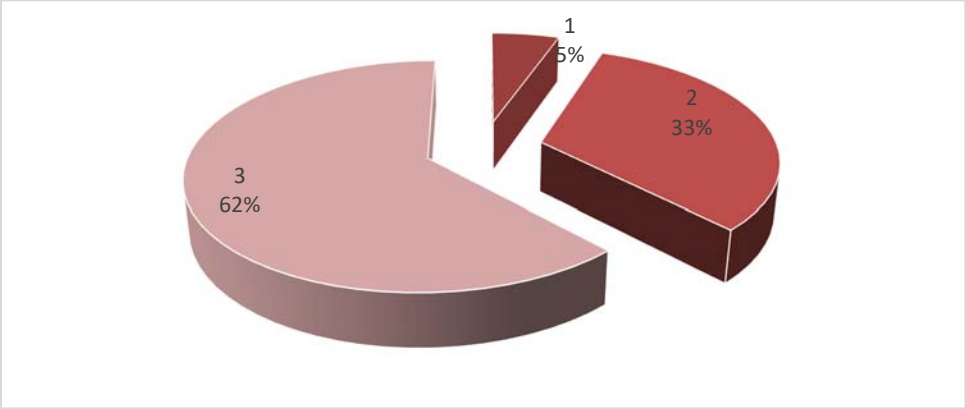
Cipher	Inhabitants of Dolon	Control
Cells with aberrations (%)	2,65	0,87 ±0,1
Total aberrations (%)	2,7±0,19*	0,87 ±0,1
Chromosome type (%)		
Total	1,95±0,16*	0,19±0,05
Dicentrics	0,05±0,02	
rings	0,23±0,05	

Translocations	0,04±0,02	0,06±0,03
Breaks, fragments, exchanges	1,62±0,15	0,13±0,05
Chromatic type (%)	0,75±0,10	0,68±0,09

As can be seen from the presented data, the frequency of chromosomal abnormalities in residents of Dolon is significantly higher ($p \leq 0.01$) than in people from the ecologically clean village of Tausugur. A comparative analysis of the types of aberrations showed that if the frequency of chromatid type aberrations in the surveyed is practically at the control level, then the frequency of chromosomal type aberrations exceeds it in 10 times, which indicates the main influence of factors of the radiation nature. Individual fluctuations in the frequencies of chromosomal aberrations were 1-7 %. The chromosome type aberrations were represented by double discontinuities and fragments, dicentrics and translocations, chromatid type - by single breaks and fragments.

A cytogenetic examination of 32 inhabitants of the village of Dolon conducted by us in 1996 (Gubitskaya et al. 1999) revealed 3.2 ± 0.23% of chromosomal aberrations, of which 2.4 ± 0.19% were chromosomal aberrations, and 0.8 ± 0.11 % chromatid. As can be seen from the presented data, there are no fundamental differences between the results obtained with a difference of 20 years ($p \geq 0,05$).

Of all the types of chromosome aberrations for diagnosis of radiation injury is most commonly used counting dicentrics, acentric fragments and centric rings, iechromosome-type aberrations. In connection with this, we carried out an analysis of the frequency distribution of chromosome-type aberrations in the people surveyed (Figure 1). It follows from the presented diagram that relatively normal frequency of chromosome type aberrations is registered only in 5% of the subjects, in the remaining 95%, the increase in cytogenetic disorders occurs mainly due to an increase in the number of biceausive chromosomal rearrangements that are markers of radiation exposure.



to 0.5% aberrations

2- 0.6 to 2% aberrations

3- 2% aberrations and above

Figure 1. Frequency distribution of chromosomal aberrations among the inhabitants of Dolon

All calculations of radiation standards do not refer to the living, surrounding people, but to the conventional "standard man" - a male of the white race, at the age of 20, with good health. There is no such "standard person" in nature. We are all different in a variety of features, including the degree of radiosensitivity (Pelevina et al. 2012). The variability of the radiosensitivity is divided into the group

sensitivity and the individual sensitivity (Snigireva et al. 2007). Analyzing the data of the cytogenetic survey of the inhabitants of Dolonin terms of group radiosensitivity of age groups, there were no significant differences in the frequency of chromosomal aberrations between individuals of different ages.

Analysis of cytogenetic data on racial radiosensitivity revealed significant differences only in the frequency of chromatid type aberrations ($p \leq 0,01$) between Asians and Europeans, but there are no differences in the overall frequency of chromosomal aberrations, and there are no significant differences between the frequencies of chromosomal aberrations detected in men and women (Table 2).

Table 2. Frequency distribution of chromosomal aberrations by race and sex

Criterion	Total aberrations	Aberrations chromosomal type	Aberrations chromatid type
Asians	2,51±0,26	2,03±0,23	0,48±0,11
Europeans	2,89±0,27	1,86±0,22	1,03±0,16
The Men	2,51±0,26	1,72±0,21	0,79±0,14
Women	2,88±0,27	2,17±0,25	0,71±0,14

As shown above, differences in group radiosensitivity were not revealed from epidemiological data. Probably, the differences in the individual reaction to irradiation are at the genetic level and are associated with the functioning or polymorphism of various genes responsible for the resistance of the organism to unfavorable environmental factors (Sal'nikova et al. 2011, Goncharova et al. 2003).

Study of the radiosensitivity of people living in Dolon

In most monitoring studies, the negative influence of environmental factors is estimated only by the frequency of chromosomal aberrations, without taking into account other genetic functions of the cells. There is a lot of data in the world literature that testify to different individual radiosensitivity. For example, a wide individual variability in the frequency of radiation-induced aberrations of chromosomes in human peripheral blood lymphocytes was observed with the same radiation load (Pilinskaya, Shemetin & Dybsky 2001). The sensitivity of people to small doses of radiation is especially great: different people differed by this factor in 6,4 times, and at doses above 2.5 Gy-only one and a half times (Plachinda 2001).

At lower dose loads, the revealed significant differences are probably due to individual differences in the response of the organism to low-dose irradiation and the non-linear nature of the dose-response of unstable chromosomal exchanges during irradiation of lymphocytes in vitro with the presence of a dose-independent plateau in the range from 0.2 to 0.4 Gy, by other authors (Demina, Demchenko & Barilyak 2009). Since the average doses of inhabitants per year were determined by physical dosimetry methods, a comparative analysis of these data and the results of the cytogenetic examination by the radiosensitivity criterion was carried out.

The entire contingent of the surveyed was allocated to the groups on the basis of the dose received for the years of residence in the studied settlements and the cytogenetic disorders detected in them. As can be seen from the presented data (Table 3), the radiosensitive individuals with the lowest dose received showed the highest frequency of chromosomal abnormalities and, on the contrary, in the stable individuals, the largest dose caused the least amount of chromosomal aberrations. The ratio of the cohort of the subjects according to the radiosensitivity criterion in the surveyed settlement is quite comparable, corresponds to the literature data (Kovalev & Smirnova 1996) and is close to the theoretically expected one.

Table 3. The distribution of the surveyed inhabitants of the village of Dolon by the radiosensitivity criterion

Radiation Sensitivity Criteria	Number of people (%)	Total aberrations	Aberrations chromosomal type	The average dose of γ-irradiation, mSv	Average age
Radiosensitive	23,0	3,88±0,33	3,50±0,31	89,2	37,1
Average Radiosensitivity	59,5	2,57±0,17	1,68±0,14	94,2	39,1
Radio-controlled	17,5	1,61±0,25	0,77±0,17	105,2	43,1

Radiosensitivity of the inhabitants of Dolon was also investigated by additional *in vitro* irradiation of peripheral blood lymphocytes of 1Gy of γ-radiation at the G_0 stage of the cell cycle (Table 4).

Radiosensitivity was assessed by the degree of increase in chromosomal aberrations after *in vitro* irradiation of lymphocytes, compared with similar data on induction of radiosensitivity in peripheral blood lymphocytes of healthy donors (18 people) under the same irradiation regimens. In the cells of people, according to their individual, genetic characteristics, there is a different radiosensitivity. The ratio of the frequency of chromosomal abnormalities detected in the examined people to the average frequency of chromosomal abnormalities in healthy donors when their blood is irradiated with a similar dose of γ-radiation is conventionally designated as the "radiosensitivity coefficient" (RC).

Table 4. A study of the radiosensitivity of lymphocytes in the inhabitants of Dolon, under the influence of 1 Gy of γ-radiation in vitro

Cipher	Inhabitants of Dolon	Control
Cells with aberrations (%)	12,38±0,38	15,0±0,80
Total aberrations (%)	13,57±0,40*	17,0±0,84
Chromosome type (%)		
Total	12,02±0,38	15,0±0,80
Dicentrics	2,68±0,19	3,0±0,36
rings	2,26±0,18	2,0±0,31
Translocations	0,41±0,07	1,0±0,22
Breaks, fragments, exchanges	6,68±0,29	9,0±0,64
Chromatic type (%)	1,55±0,14	2,0±0,31

The radiosensitivity of the inhabitants of Dolon village when using a dose of 1 Gy based on the number of cells carrying chromosomal aberrations on the average in the group was significantly lower 13.57-0.40% than in healthy donors 17.0-8.4% (Table 4) ($p \leq 0.01$). At the same time in the control group, the majority of those surveyed have a RC in the range of 0.8-1.2, in Dolon residents 0.5-0.9, which indicates the adaptability of the surveyed population. Development of radio resistance with additional *in vitro* irradiation was recorded in almost 40% of the subjects, radio sensitization was registered in only one person (RC 1.29). In addition, in both groups there are dips of radio-resistant and peaks of radiosensitive individuals. The distribution of the individuals surveyed by the radiosensitivity criterion made it possible to identify in individuals with an average radiosensitivity the

relationship between the spontaneous frequency of chromosomal aberrations and RC with additional in vitro irradiation (Figure 2).

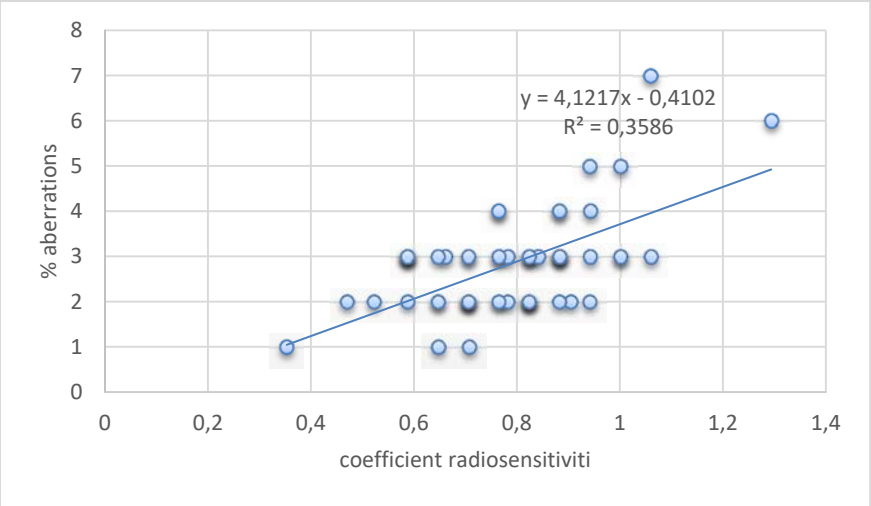


Figure 2. The relationship between the spontaneous frequency of chromosome aberrations and the radiosensitivity coefficient

Dose evaluation and mathematical modeling

The purpose of many monitoring works on the cytogenetic analysis of people exposed to radiation is the issue of biodosimetry. Biological dosimetry on chromosome aberrations in lymphocyte culture provides reliable information in cases of relatively uniform acute irradiation, but with uneven exposure with a dose drop of more than 2 to 3 times, the informative value of the indicator decreases (Vinnikov et al. 2010). Quantitative retrospective dose assessment for chromosomal aberrations in chronically irradiated people and in the long term after exposure to radiation meets even greater difficulties (Crespo, Domene & Rodríguez 2011, Vinnikov et al. 2011).

There are several main methods for retrospective assessment of external exposure doses (Lloyd, Edwards & Leonard 1992, IAEA 2014, Snigireva 2011, Semenov, Vorobtsova & Zharinov 2010, Martins, Antunes & Monteiro 2013), in the frequency of dicentrics and centric rings. For this type of aberration, the mean group accumulated dose of radiation was calculated (Table 5).

Table 5. Calculation of the average group accumulated radiation doses from the frequency of dicentrics and centric rings

Frequency of dicentrics and rings	The dose of internal accumulated radiation Sv (Gy)		
	According to the Lloyd D=y/0,022	$Y=\alpha D+\beta D^2$ (IAEA)	$y=0,1+1,5\ D+6,3\ D^2$(2)
0,28	0,13	0,15	0,09

The peculiarity of biological methods (in this case cytogenetic) is that the reaction of the organism to radiation exposure, mediated by specific characteristics of the organism, is assessed primarily by individual radiosensitivity. The "biological" dose is thus an integral indicator of the damaging effect of radiation, conditionally expressed in terms of the effective dose, therefore, when assessing individual doses, it is necessary to take into account individual radiosensitivity with the help of certain correction factors.

Based on the estimation of doses with the help of chromosome aberrations and the estimation of radiation doses obtained with the help of physical dosimetry methods, a comparative analysis of the calculation of individual doses of ionizing radiation of residents was carried out.

The obtained correlation values, as well as the pattern of the scattering diagram, suggest that there is no linear relationship between the dose obtained and the cytological survey data for the inhabitants of the surveyed settlement.

For example, the correlation between the radiation dose and the frequency of aberrations in all, and the frequency of chromosome-type aberrations, was 0.007 and 0.11 for the inhabitants of Dolon, which shows the absence of any significant linear connection. The addition of quadratic terms did not change the situation i.e. the construction of a regression model for such a dataset is not possible. However, if we split the reaction of people on radiation (as was demonstrated above) by three signs of gradation (radiostable, medium radiosensitive, radiosensitive), in this case one can see a certain relationship between the frequency of chromosomal disturbances and radiation dose (Table 6).

There is a fairly high correlation in the surveyed residents of Dolon between the frequency of disturbances and the radiation dose for the average radiosensitive and radiosensitive individuals 0.70 and 0.55, $\beta \geq 0.999$, respectively. For radio-resistant people, low correlation values may be due to the fact that the dose to a lesser extent will affect them according to the very definition of radio-resistant individuals.

This approach allowed us to introduce dummy variables for regression analysis, such as the gradation of the radiosensitivity feature. On the basis of the obtained calculations, the table presents regression equations that take into account the overall frequency of chromosomal aberrations and the frequency of chromosome-type aberrations, taking into account the sensitivity level (Table 6).

Table 6. Regression equations that take into account the overall frequency of chromosomal aberrations and the frequency of chromosomal aberrations

Level of radio stability	Linear regression model	r^2	p
Radio-controlled	$Y = 285.971 + 22.297 \times A + 3.213 \times B$	0,15	0,4
Medium-radio-resistant	$Y = 170.082 - 6.584 \times A + 81.425 \times B$	0,51	0
Radio sensitive	$Y = 171.20 + 43.19 \times A - 18.07 \times B$	0,33	0,06
A - the percentage of aberrations of all; B - the percentage of chromosomal aberrations; Y - the dose received by the inhabitant of the village			

The above models demonstrate a significant coefficient of determination, (the share of the variance of the dependent variable, explained by the model of dependence) only for the middle-sensitive inhabitants of the Dolon settlement. In this regard, we also used a dose-estimation approach taking into account the radiosensitivity based on the use of calibration curves.

The dose-response relationship for human lymphocytes was obtained with γ-irradiation using a ^{60}Co radiation source at a dose rate of 0.1 Gy / min. To create a calibration curve, doses in the range from 0.01 to 1Gy (0.01, 0.05, 0.1, 0.3, 0.5 and 1 Gy) were used. As shown above (Table 7), the effects of radiation doses on people chronically exposed to radiation and healthy donors differ slightly, and the challenge before us is to estimate the doses for chronically irradiated people. Therefore, in order to construct the most appropriate dose-effect calibration curve, the results of a cytogenetic study for 18 people from an irradiated cohort were analyzed. However, the response to doses in the examined people was different and varied widely for each dose (Table 7).

Table 7. Variations in the frequency of chromosomal aberrations for each dose in different individuals

Dose, Gy	0,01	0,05	0,1	0,3	0,5	1
Min Aberration	2	3	3	5	8	10
Max aberrations	7	10	9	11	14	25

This approach to the separation of the surveyed people on the basis of radiosensitivity makes it possible to hope for a more reliable regression analysis and to reveal a stronger interrelationship between the frequency of disorders in lymphocytes and the dose of irradiation than without taking into account the sign of radiosensitivity.

In the case of acute human irradiation, linear and linear-quadratic models of the dose dependence of these aberrations, obtained with a single irradiation of lymphocytes in vitro, are used as calibration. If the irradiation is fractionated or prolonged, then the use of such models requires the introduction of certain corrections. In direct experiments it was shown that a decrease in dose rate leads to a decrease in the quadratic coefficient of the linearly quadratic dose-effect equation, with a relative linearity. Analysis of the dose-effect equations from 16 papers by different authors obtained by irradiation of lymphocytes in vitro (γ-radiation, ^{60}Co) showed that when the dose rate decreases below 0,002 Gy / min the quadratic coefficient tends to 0, and the dose-dependence model turns into a linear (Cerqueira et al. 2004).

In this connection, equations for the approximation of a linear function for radiosensitive, mid-sensitive and radio-resistant individuals are presented. However, with greater reliability for radiosensitive and radio-resistant individuals, the obtained indices are described by the equations of approximation of the polynomial function.

Table 8. Equations of approximation of the linear and polynomial function of the frequency of chromosomal aberrations for radiosensitive, mid-sensitive and radioresistant individuals

Level of radio stability	The polynomial model	r^2
Radio-controlled	$У=-8,645x^2+17,67x+0,008$	0,992
Medium-radio-resistant	$У=-3,089x^2+14,15x+1,136$	0,920
Radio sensitive	$У=9,194x^2+8,111x+2,809$	0,991
	Linear model	
Radio-controlled	У=9,343x+0,669	0,930
Medium-radio-resistant	У=11,18x+1,365	0,914
Radio sensitive	У=16,96x+2,105	0,969

Thus, the calculation of doses for radiosensitive people with the help of an equation with decreasing, and for radio-stable ones with increasing coefficients, will lead to a relatively real estimate of the doses, the same for the population under study living in the same conditions (Table 8).

Using these calibration curves and regression equations based on the results of a cytogenetic examination, it is possible to calculate individual accumulated doses with some approximation. At the same time, based on the individual variation in the frequency of chromosomal aberrations (1-7%) without taking radiosensitivity into account, the absorbed radiation dose varies from 0 to 0.3 Sv (Gy). Taking into account the degree of radiosensitivity of the examined individuals indicates that the average absorbed radiation dose of individuals in Dolon is 0.11 Sv (Gy), which corresponds to the results of the determination of the mean dose calculated from the frequency of dicentrics. The

advantage of the conducted studies and the presented models is that using them on the frequency of chromosomal aberrations one can determine the individual absorbed dose by taking into account the radiosensitivity. This also does not take into account such important factors as the real dose rate, the nature of the radiation exposure, the distribution of the dose in time, etc.

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