

**ASSESSMENT OF OCCUPATIONAL EXPOSURE AND INDIVIDUAL
RADIOSENSITIVITY IN PEOPLE EXPOSED TO RADIATION USING METHODS OF
PHYSICAL AND BIOLOGICAL DOSIMETRY**

Oksana G. Cherednichenko¹, Elena G. Gubitskaya¹, Mara M. Bitenova², Sergei N. Lukashenko²,

Anastasiya L. Pilugina¹

¹ Institute of General Genetics and Cytology, Kazakhstan, Almaty, str. Al-Farabi 75A

² Institute of Radiation Safety and Ecology, Kazakhstan, Kurchatov

Abstract

This paper examined people professionally in contact with sources of ionizing radiation. The incidence of chromosomal aberrations, the radionuclide content in the urine of the radiochemical method and calculation of internal doses based on the results of direct measurement of the concentration of incorporated radionuclides ¹³⁷Cs and ²⁴¹Am using human radiation spectrometer (HRS). According to the results of physical and biological dosimetry identified individual cumulative doses and the ratio defined cohort surveyed by radiosensitivity

Key words: *chromosomal aberrations, physical methods of dosimetry, radiation sensitivity, ionizing radiation, biodosimetry*

Questions of control of intake of radioactive materials in a human body and their contents in an organism were and remain the most significant in a problem of radiation protection of the personnel of the enterprises of nuclear branch. It is caused by that radioactive materials are capable to collect in an organism, to be redistributed in fabrics, reaching in separate bodies of levels which can be unsafe for health. Information on amount of the radionuclide which has arrived in an organism is a basis at determination of potential danger of internal radiation of the personnel. One of the major tasks when determining dose loadings from receipt in an organism of radionuclide are the accuracy of an assessment of the content of radionuclide in an organism direct and indirect methods.

The main method of biodosimetry is the analysis of cytogenetic damages to lymphocytes of peripheral blood of the person (Zakeri & Hirobe 2010, Snigireva 2011). At radiation of cells of the same donor of in vitro strict dependence of frequency of aberrations on radiation dose is observed. It gave the grounds for use of this criterion for biodosimetry (Shmakova 2006). However the researches in vivo were other than those in vitro, and results of biodosimetry often don't coincide with the doses recorded documentary on indications of dosimeters (Swartz 2010). Thus radiobiologists are inclined to consider as more reliable information received by means of biological methods, and draw a conclusion about the wrong calculation of dose loadings, forgetting about genetic distinctions of individuals. It is known that individuals not only the same look, but even the same population can differ considerably on radiosensitivity.

Results of radiation influences at the level of an organism are influenced by a huge number of factors, among which condition of biochemical and physiological systems, existence of hereditary diseases etc. At chronic radiation such population processes, as, for example, elimination of damages to a course of physiological updating of cellular structure, and mainly is eliminate cages with violations are added. Thus in populations there can be multidirectional processes. On the one hand, there is an adaptation – selection and reproduction of cages to more resistant genotype that leads to decrease in radio sensitivity of population. On the other hand, emergence of the genetic instability leading to increase of frequency of genetic violations in the following generations is possible.

At an assessment of averages and the collective doses received by populations, exposed to radiation, it is possible to believe that influence of all listed factors is averaged therefore use of existing methods of biodosimetry in this case can be quite correct. However when determining by these methods of individual doses there can be essential mistakes that dictates need of development of more perfect ways of an assessment of genetic effects of ionizing radiation at the person taking into account his specific features, and also carrying out complex researches taking into account genetic, physical and radiochemical methods of dosimeter.

In represented work level of cytogenetic violations, taking into account the dose loadings estimated by physical and radiochemical methods, at the people who are professionally contacting to tests, containing radionuclide's, various intensity of radiation is studied. And also the biodosimetric assessment on the basis of the received results and comparison of data on biodosimetry and physical parameters of the saved-up dose loadings is carried out.

The people who are professionally contacting to sources of ionizing radiation (81 persons) are surveyed. On degree of professional harm they are divided into the persons contacting with background (13 people) and radioactive tests (68 people, conducting laboratory and field researches). As control group of comparison data on cytogenetic inspection of 42 inhabitants of the environmentally friendly settlement Tausugur of Almaty area are used.

Frequency of chromosomal aberrations (Moorhead et al. 1960), the content of radionuclide (^{40}K , ^3H of ^{137}Cs , ^{241}Am , ^{90}Sr and $^{239+240}\text{Pu}$) in urine by a radiochemical method (Institute of Radiation Safety and Ecology 2010) and direct measurement of concentration of the incorporated ^{137}Cs radionuclide and ^{241}Am with use of the human radiation spectrometer (HRS) - a direct method, for calculation of doses of internal radiation (International Atomic Energy Agency 2000) were studied.

For an assessment of doses of internal radiation by results of the content of radionuclide in urine methods recommended IAEA and MKRZ and the software of MONDAL3 recommended by IAEA are used (International Atomic Energy Agency 2004, Vlasov 2009). In the 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 (Plohinsky 1967).

STUDYING OF FREQUENCY OF CHROMOSOMAL ABERRATIONS IN LYMPHOCYTES OF THE PEOPLE WHO ARE PROFESSIONALLY CONTACTING TO TESTS, CONTAINING RADIONUCLIDE OF VARIOUS INTENSITY

The cytogenetic analysis of the people who are professionally contacting to sources of ionizing radiation revealed that the frequency of chromosomal violations at the people contacting to background tests is nearly 3 times higher, than people from the environmentally friendly settlement have Tausugur ($p \leq 0,01$) (table 1).

The comparative analysis of the obtained data on types of aberrations showed that the frequency of aberrations of chromatic type is practically at the level of data from the item Tausugur. At the same time the frequency of aberrations of chromosomal type increased almost by 10 times ($p \leq 0,01$) that points to primary influence of genotoxicant of the radiation nature.

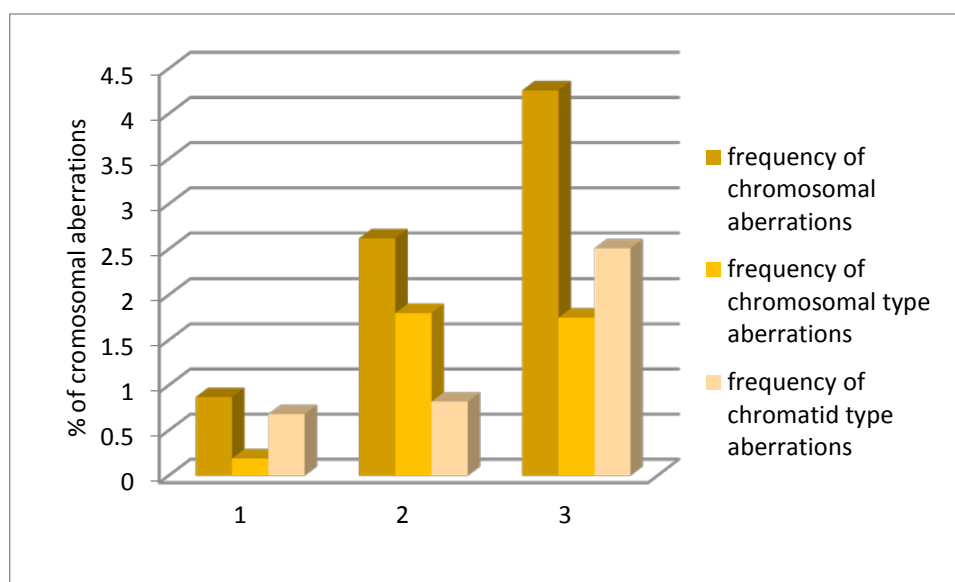
The analysis of results of cytogenetic inspection of the people who are professionally contacting to radioactive tests ($4,27 \pm 0,17\%$), showed double increase in frequency of chromosomal aberrations in comparison with the colleagues contacting to background tests ($2,62 \pm 0,29\%$) ($p \leq 0,01$) (figure 1). However this increase occurs at the expense of increase in aberrations of chromatid type while the frequency of aberrations of chromosomal type – the indicator of radiation influence practically didn't change. Possibly, it is connected with influence of the general radiation background and use in the professional purposes as well chemicals of high mutagen potential. Individual fluctuations of frequencies of chromosomal aberrations made 1-8%.

Aberrations of chromosomal type were presented by double gaps and fragments, dicentrics and translocations, chromatid type - single gaps and fragments.

Table 1 - Cytogenetic study of people professionally contact samples with varying intensity of radiation

Option	Cells with aberrations (%)	The frequency of aberrations (%)	Types of aberrations (%)				
			Chromosomal type				Chromatid type
			Only	Breaks, fragments	Dicentric	Translocation	
Contact with the background samples	$2,5 \pm 0,28$	$2,62 \pm 0,29$	$1,8 \pm 0,24$	$1,62 \pm 0,23$	$0,08 \pm 0,05$	$0,1 \pm 0,05$	$0,82 \pm 0,16$
Contact with	$4,09 \pm 0,17$	$4,27 \pm 0,17$	$1,75 \pm 0,1$	$1,41 \pm 0,1$	$0,1 \pm 0,03$	$0,24 \pm 0,05$	$2,51 \pm 0,14$

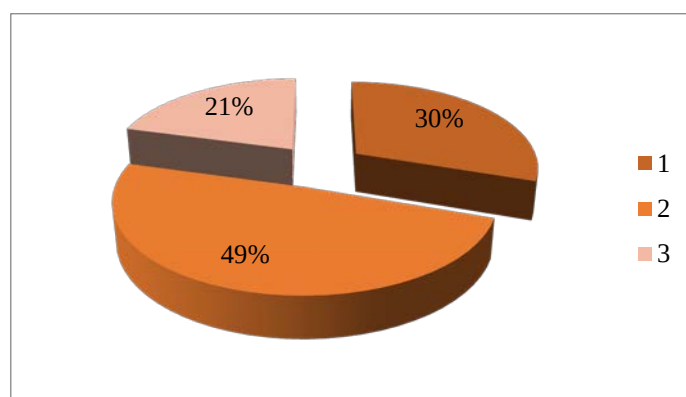
radioactive probes							
control, village Tausugur	$0,87 \pm 0,1$	$0,87 \pm 0,1$	$0,19 \pm 0,05$	$0,19 \pm 0,05$	-	-	$0,68 \pm 0,09$



1. Control, village Tausugur;
2. Contact with the background samples;
3. Contact with radioactive probes;

Figure 1 - Distribution of Structure of Chromosomal Aberrations at the surveyed groups of the professionals contacting to background and radioactive tests

At systematization of frequency of chromosomal aberrations in lymphocytes of peripheral blood the surveyed contingent was divided into three groups: the persons having chromosomal aberrations in lymphocytes of peripheral blood to 2%, from 2 to 4% and of 5% and above. The first group (1) includes a cohort of the people having spontaneous level, the second (2) – raised and the third (3) – high level of chromosomal aberrations (figure 2). Only at 1/3 studied persons (30%) the frequency of the revealed violations didn't exceed all-population spontaneous level for Kazakhstan, at a half (49%) it was raised and at 1/5 (21%) – high. In total at 70% of the chromosomal aberrations surveyed frequency I exceeded spontaneous level by 2-5 times.

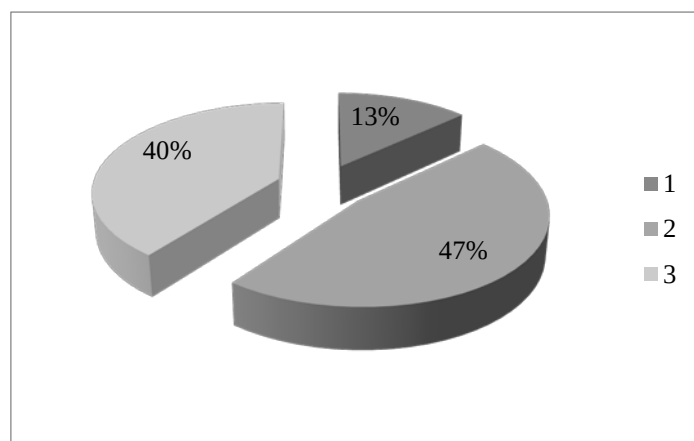


1. to aberrations 2%

2. from 2,1% to 4,9 % aberrations
3. 5% % or higher aberrations

Figure 2 - Distribution of frequencies of chromosomal aberrations at the people, professionally contacting tests of various intensity radiation

From all types of aberrations of chromosomes for diagnostics of radiation defeats calculation of aberrations of chromosomal type is most often used. In this regard we carried out the analysis of distribution of frequencies of aberrations of chromosomal type on increase degree from control indicators (figure 3). When comparing charts presented in figures 2 and 3 it is visible that number of people having the average level of frequency of aberrations of chromosomal type practically didn't change, however the group of people with low level of frequency of aberrations of hromatid type considerably decreased and increased with high frequency. It once again testifies that the increase in cytogenetic violations at the surveyed cohort occurs generally due to increase of number of two-shock chromosomal reorganizations (dicentrics, rings, translocations, double gaps and fragments), being markers of radiation influence.



1. to aberrations 0,5%
2. from 0,6 % to 2 % aberrations
3. 2% % or higher aberrations

Figure 3 - Distribution of Frequencies of Aberrations of Chromosomal Type at the people, professionally contacting tests of various intensity

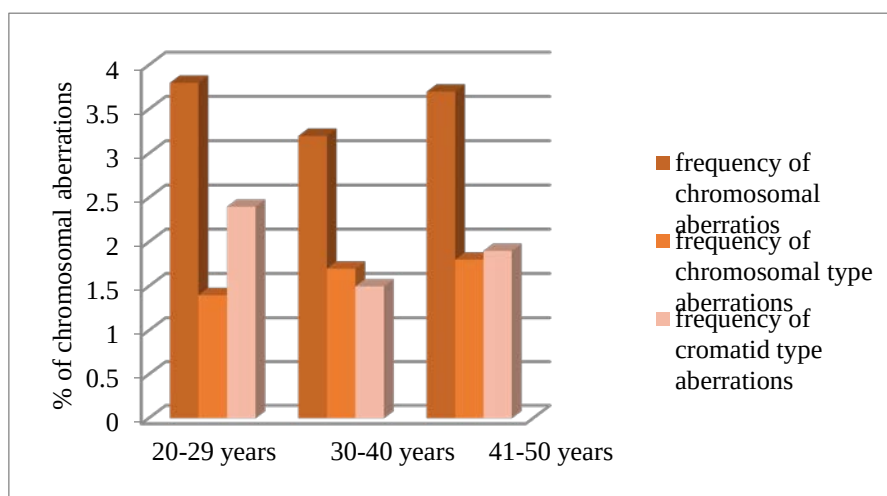


Figure 4 - Distribution of frequency of chromosomal aberrations on age groups

All calculations of radiation norms concern not to live people surrounding us, and to conditional to "the standard person" - the man of white race, at the age of 20 years, with a good shape of health. It is clear, that such "the standard person" in the nature doesn't exist. All of us are various on a set of signs, including on degree of radio sensitivity (Kovalev & Smirnova 1996).

Having analyzed data of the conducted cytogenetic examination of "professionals" in respect of group radio sensitivity of age groups it is shown that reliable distinctions on the frequency of chromosomal aberrations between individuals of different age it isn't revealed (figure 4).

Possibly, distinctions in individual reaction to radiation are covered at genetic level (Sal'nikova et al. 2008, 2010) and are connected with functioning and polymorphism of various genes of (Sal'nikova et al. 2011) organisms responsible for stability to adverse factors of environment (Spitkovsky et al. 2003, Tomilin 2002, Goncharova 2003).

As it was shown above, high variability of frequency of chromosomal aberrations at the studied group of people is observed. As their work is connected with a certain nature of works possibly, and they are exposed to various radiation influence, the analysis of dependence of frequency of chromosomal aberrations from a type of work – laboratory and field researches (figure 5) is carried out.

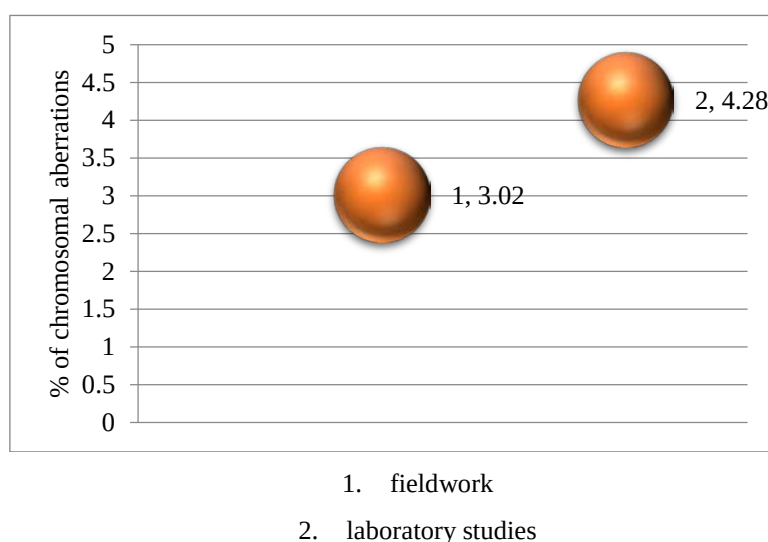


Figure 5 - Distribution of frequency of chromosomal aberrations from a type of work

Apparently from the presented data at the personnel occupied with processing of tests in vitro ($4.28 \pm 0.45\%$) the frequency of chromosomal violations authentically ($p \leq 0.05$) exceeds this indicator at people taken with field researches ($3.02 \pm 0.38\%$), in this case probably the leading role is played by limitation of space and respectively increased concentration of radionuclide.

There are some main techniques of a retrospective assessment of doses of the external radiation, (Snigireva 2011) most often different authors use the frequency of dicentric and centric rings. In the carried-out cytogenetic analysis of professionals this type of aberrations was found only in some surveyed in spite of the fact that at each individual it was seen from 200 to 400 cages. In this regard on this type of aberrations the middle group saved-up dose of radiation was calculated. The following techniques were applied: 1-on Lloyd's initial formula: $D = y/0.022$ (Lloyd et al. 1998), where D – a dose of the internal saved-up radiation (Gy), at – the frequency of dicentric on 1 cage, 0.022 standard coefficient; 2 - to formula recommended to International Atomic Energy Agency (2001) for the fractioned radiation: $Y = \alpha D + \beta D^2$, where: D – dose of the internal saved-up radiation (Gy), Y – the frequency of dicentric on 1 cage, α – 0.03 (coefficient), β – 0.06 (coefficient); 3 - calibration curves a dose - the effect, received at radiation of samples of blood by gamma radiation with a power of dose of 0.1 of Gy / min. The corresponding regression dependence, has an appearance: $y = 0.1 + 1.5 D + 6.3 D^2$ where y - the frequency of aberrations is at 100 cages, D - a dose of radiation (Demina et al. 2009). Using various methods of an assessment of doses results presented in table 2 were received. For comparison

data on calculation of doses of people from the settlement Sarzhal relating to a "extraordinary" zone of radiation risk, owing to influence of the Semipalatinsk proving ground are provided (table 2).

Table 2 - Calculation of group average accumulated doses of radiation frequency of dicentrics and centric rings

Variant	Dicentric frequency on cell 100	Accumulated dose of internal irradiation (frequency of dicentrics and rings) Sv (Gy)		
		Lloyd formula $D=y/0,022$	$y = 0,1 + 1,5 D + 6,3 D^2$	$Y=\alpha D+\beta D^2$ (IAEA)
People professionally exposed to radiation	0,10	0,045	0,01	0,032
Village Sarzhal	0,16	0,072	0,02	0,05

On the basis of it, proceeding from the general frequency of dicentrics on group, it is possible to define that the average dose received by the personnel, makes about 0,03 Sv (Gy).

As our task consisted in carrying out comparative individual dosimeter by means of physical and biological methods for a dose assessment we used various calibration curves and the equations of regression based on the general frequency of chromosomal aberrations, received at radiation of samples of blood by gamma radiation with a power of dose of 0,1 of Gy/min (Demina et al. 2009). Using these calibration curves with some share of approach it is possible to calculate the individual saved-up doses. Thus if to proceed from an individual variation of frequency of chromosomal aberrations (1-8%) the absorbed dose of radiation also varies from 0 to 0,3 Sv (Gy).

Values of doses were calculated by means of various methods. Thus we didn't consider such important factors, as the real power of a dose, nature of radiation influence (internal or external radiation), dose distribution in time, etc. as such data are absent. It is natural that there is the big share of uncertainty connected with influence on level of chromosomal aberrations of various factors of not radiation nature. Feature of biological methods, in this case cytogenetic, consists that reaction of an organism to the radiation influence, mediated by specific characteristics of an organism, first of all individual radiosensitivity is estimated. The "biological" dose thus is an integrated indicator of damaging action of radiation, conditionally expressed in terms of an effective dose therefore at an assessment of individual doses it is necessary to consider individual radio sensitivity by means of certain correction coefficients.

ASSESSMENT OF THE INDIVIDUAL SAVED-UP DOSES METHODS OF PHYSICAL DOSIMETER AT THE PEOPLE WHO ARE EXPOSED TO RADIATION INFLUENCE OWING TO THE PROFESSIONAL ACTIVITY

Actual problem of radiation hygiene – development of reliable lifetime methods of an assessment of receipt and the content of radioactive materials in a human body for the subsequent carrying out an assessment of doses of internal radiation.

The solution of problems of control of internal radiation of the person shares on two main stages: definition of the contents (intake) of radionuclide in an organism; calculation of doses of internal radiation for any period from the moment of receipt before full removal of radionuclide from an organism (Stepanenko 2011).

As a result of professional activity in the territory the personnel SNTS is affected by chronic radiation due to inhalation intake of technogenic radionuclide together with inhaled air, and also their peroral receipt owing to inadvertent swallowing the firm particles containing in a production dust. Having estimated the content of natural radionuclide in an organism, it is possible to carry out control and the accounting of dose loadings of the personnel which is carrying out works in the territory SNTS.

For carrying out an assessment of concentration incorporated, as a result of professional activity of radionuclide, measurements of group of staff of the institute belonging to category of the personnel of group "A", after carrying out field works by them in the field camp located on a platform "Skilled field" were executed. This platform is characterized by the highest superficial pollution by artificial radionuclide (^3H , ^{137}Cs , ^{90}Sr , $^{239+240}\text{Pu}$ and ^{241}Am) in the territory SNTS. In spite of the fact that employees when working use means of individual protection, they are in group of the increased risk.

The platform "A skilled field" represents a large-scale complex of the construction constructions intended for carrying out tests and registration of parameters of nuclear explosion in the conditions of natural experiment. In

venues of land tests there are funnels with *навалами* soil and fragments of the melted-off soil containing products of nuclear explosions. Dose power on the naval of some funnels exceeds 40 $\mu\text{Sv/h}$. In tests of the soils selected near funnels, technogenic radionuclide ^{137}Cs , ^{241}Am , ^{60}Co , ^{152}Eu , ^{154}Eu , ^{90}Sr , $^{239+240}\text{Pu}$ were found.

Specific activity of radionuclide in a soil and vegetable cover in venues of nuclear tests on a platform "A skilled field" reaches the following sizes: ^{60}Co , ^{154}Eu , ^{155}Eu – $\text{nx}10^2$ of Bq/kg, ^{137}Cs $\text{nx}10^5$ of Bq/kg, ^{241}Am – $\text{nx}10^5$ of Bq/kg, ^{90}Sr – $\text{nx}10^6$ of Bq/kg, $^{239+240}\text{Pu}$ – $\text{nx}10^7$ of Bq/kg.

Definition of amount of the incorporated radionuclide is made, as a rule, in two ways. Typical methods of individual monitoring of intake of radionuclide in an organism are: the account of radiation of an organism as a whole, the gamma radiation consisting in detecting which is let out by incorporated radionuclide, by means of human radiation spectrometer (HRS) and the analysis of tests of allocations.

Researches of the content of radionuclide in an organism of surveyed persons with application of an indirect method - definition of the content of radionuclide ^{40}K , ^3H , ^{137}Cs , ^{241}Am , ^{90}Sr and $^{239+240}\text{Pu}$ in urine are conducted. According to the received results follows that the contents ^3H , ^{137}Cs , ^{241}Am , $^{239+240}\text{Pu}$ and ^{90}Sr is in tests of urine of the personnel below limits of detection of measuring equipment. The contents ^{40}K in tests of urine of the personnel are in limits of 12 - 152 Bq/l. According to the available data, natural volume activity ^{40}K in urine makes, on the average, 56 – 74 Bq/l. (International Commission on Radiological Protection 1997). It is revealed that the contents ^{40}K in some tests of urine, exceeds this value, and at some persons it was observed till a field season, at others after. It agrees, to methodical approaches, the assessment of receipt ^3H , ^{137}Cs , ^{241}Am , $^{239+240}\text{Pu}$ and ^{90}Sr and expected dose loadings is carried out. As all results on specific activities ^3H , ^{137}Cs , ^{241}Am , $^{239+240}\text{Pu}$ and ^{90}Sr in urine, are below detection limits, for an assessment of expected dose loadings the minimum limits of detection are taken. Calculation of an expected effective dose of internal radiation was made for a peroral and inhalation way of intake of these radionuclides to an organism (Bryantseva 2010). The assessment of doses of internal radiation by results of research of radionuclide in urine made: $^3\text{H} < 3,6 \cdot 10^{-7}$; $^{137}\text{Cs} < 1,3 \cdot 10^{-6}$; $^{241}\text{Am} < 1,7 \cdot 10^{-2}$; $^{239+240}\text{Pu} < 4,2 \cdot 10^{-3}$; $^{90}\text{Sr} < 1 \cdot 10^{-6}$ mSv / year.

Further determination of activity of radionuclide in a human body is carried out with use of human radiation spectrometer (HRS) the Spectrometry of radiation of the person belongs to direct methods of definition of radionuclide in a body of the person and allows to find existence in an organism as natural radionuclide (^{226}Ra , ^{232}Th , $^{210,212}\text{Pb}$, $^{212,214}\text{Bi}$, ^{40}K , $^{235,238}\text{U}$), and radionuclide of a technogenic origin (^{60}Co , $^{134,137}\text{Cs}$, ^{241}Am) (Scientific production department All-Russian Scientific Research Institute of Physico-Technical Measurements 1991). By results scale - spectrometer measurements of activities ^{241}Am and ^{137}Cs the received values in all cases lie below a detection limit, thus the limit of detection made for ^{137}Cs - from 0,03 Bq/kg to < 0,14 Bq/kg, for ^{241}Am - from 0,11 Bq/kg to < 0,3 Bq/kg. Various levels of definition for various surveyed groups are caused by an individual difference in growth, weight and measurement time (Kutkov & Tkachenko 2001).

With use of the top limits of detection on ^{137}Cs and ^{241}Am the assessment of expected dose loadings of radionuclide of the surveyed personnel which is carrying out economic activity on was carried out SNTS. By results of a conservative assessment the expected effective dose of internal radiation of the personnel from ^{137}Cs doesn't exceed $2,7 \times 10^{-4}$ mSv/year, from ^{241}Am – 0,2 mSv/year.

On the basis of results of direct and indirect measurements it is possible to estimate the dose of internal radiation making an integral part of any program of radiation protection which helps to guarantee acceptable level of safety and satisfactory conditions in the radiological relation on a workplace. Range of doses of internal radiation made from 0,004 to 1,465 mSv. Range of doses of the external radiation, measured by means of thermo luminescent dosimeters made from 0,3 to 1,406 mSv. Thus, it is obvious that the total effective dose of internal radiation of the personnel doesn't exceed an admissible limit of a dose for the personnel - 20 mSv in a year on the average for any consecutive 5 years, but no more than 50 mSv in a year (Bryantseva 2010).

Analyzing data of physical dosimeter reliable correlation (0,71 is observed; $n=21$, $\beta \geq 0,999$) between the calculated effective doses of radiation by means of direct and indirect methods of physical dosimeter and the registered dose of radiation in a year according to individual dosimeters. Between the calculated and received doses in 5 years correlation communication is absent and makes 0,41; $n=21$, $\beta \leq 0,95$).

On the basis of the carried-out assessment of doses by means of chromosomal aberrations and an assessment of the saved-up doses methods of physical dosimeter carried out the comparative analysis of calculation of individual doses by different methods with use of the doses of ionizing radiation received by the personnel for the last year and 5 years.

Correlations between the frequency of chromosomal violations and the dose of radiation registered by dosimeters in a year or the dosimeter calculated by means of physical methods it isn't revealed. Possibly, it is connected with heterogeneity surveyed by criterion of radio sensitivity. If population was genetically "ideal"

(that is infinite on the number in which all individuals would have equal probability of a contribution of the genes in the following generation), about 50% of individuals would have to get to a zone of average value of a sign. Supersensitive and super steady would have to make on 2,5% of population. Other 22,5% would concern to more radio sensitive, than on the average, other 22,5% - to more radio resistant, than on the average. These theoretical calculations are far from reality as "ideal" populations don't exist. Real populations always have limited number, and panmixis (free crossing) in them is never reached as a result of social, economic, moral and ethical and other restrictions (Yablokov 2002).

In the report given on individual variability of radio sensitivity of mammals (Kovalev & Smirnova, 1996) it is shown that in human populations there is a range of distribution of individuals by this criterion: the most part of individuals is characterized by average sensitivity to action of ionizing radiation, 14 - 20% are much more radio resistant, and 10 - 20% - much more radio sensitive. The difference in reaction to radiation between hypo - and hyper sensitive individuals can be repeated. For example, wide individual variability on the frequency of the aberrations of chromosomes caused by radiation in lymphocytes of peripheral blood of the person is found at identical radiation loading (Pilinski 2001). Sensitivity of people to small doses of radiation is especially great: different people differ on this sign by 6,4 times, and at doses over 2,5 Gr - only by one and a half times (Plachinda 2001).

On the basis of these yielded and the comparative analysis of results of definition of doses methods of physical and biological dosimeter we carried out the correlation analysis of results of the people, being characterized average sensitivity to action of ionizing radiation, having thus excluded radio sensitive and radio steady individuals. At people with average radio sensitivity reliable positive correlation ($0,705, \beta \geq 0,999$) between the sizes of doses determined by results of the cytogenetic analysis and effective doses, calculated on the basis of direct and indirect methods of physical dosimeter is observed. The ratio of a cohort surveyed by criterion of radio sensitivity in our research was distributed as follows: radio sensitive (11,5%) – average radio sensitivity (73,1%) – radio steady (15,4%) that fully corresponds to literary data (Busby et al. 2010).

Thus, the carried-out cytogenetic analysis of the people who are exposed to ionizing influence, owing to the professional activity revealed high frequencies radiation the induced chromosomal aberrations. High variability of frequency of chromosomal aberrations at surveyed, not correlating with the size of the received dose, testifies to heterogeneity of population by criterion of radio sensitivity. In this regard, the main problem at interpretation of results of individual dosimeter is reduced to various reactions of people to radiation and considerable divergences in an assessment of doses by physical and biological methods that dictate, in some cases, need of quantitative definition of individual reaction and its account at calculation of a dose of the received radiation.

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