New methodical approach for calculation of the individualized internal doses of persons affected due to the Chernobyl accident

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The basis of methodical approach for calculation of the individualized internal doses is the con-firmed original scientific hypothesis that every group of individuals which are homogeneous on demographic characteristics (gender and age), on a curve of dose distribution that is constructed according to the data of individual measurements of Cs137 in the human body (WB measurements), has the determined location, thus, that is constant in time, i.e. percentiles of dose distribution corresponding to the average internal dose of every age group of men and women on a curve of dose distribution occupy the certain, steady in time, location.

Keywords: *individualized internal dose, percentile of dose distribution, stability.*

Introduction

One of the most actual problems for conducting radiation-epidemiological studies on the establishment of dependence "dose-response" and evaluation of radiation risk is the evaluation of individual accumulated since the Chernobyl accident radiation doses of the population living in the contaminated areas.

State Register of persons exposed to radiation from the Chernobyl disaster (Gosregister) is the main instrument of the radiation-epidemiological studies on the establishment of dependence "dose-response" and evaluate long-term effects of radiation risk exposure. The data on the health status of ~ 250,000 individuals contains in the State Register. Individual passport details and information about radiation doses are absent.

The correct dose assessment can be made based on studies of regularities of formation of population doses.

Formation of doses of external and internal exposure varied considerably. A monotonic decrease with time characterize for external dose and determine by the radioactive decay of long-lived radionuclides and redistribution in the soil profile. Considerable variability characterize for internal dose. Besides, of radioecological factors individual internal dose depends on the level of food consumption and growth of local production. It is determined by the individual's personal characteristics such as gender, age, profession et al. [1].

Existing methods for evaluating of individualized doses based on radioecological modeling [2, 3]. The error of this method was 200 – 300% for calculating the mean group dose. Methodical approach individualized assessment of internal doses [4] was calculating of individualized internal doses according to the value of the corresponding quartile distribution of annual individual dose. It is provides a high prediction accuracy. However, its drawback is that data of the emission spectrum of human from an individual or a family member for one or few years is requires. The State Register do not consist data for all people. The procedure for calculating is quite laborious.

The purpose of this study: to reveal the regularities of individual internal dose in individuals living in the territory contaminated by radionuclides based on the data of WB measurements, depending of individual's personal characteristics and on their basis to develope a new methodological approach assessment individualized internal doses.

Materials and methods

Materials of the study were:

- the Database of the WB measurements of residents of the Republic of Belarus for the 1987-2008, the register of certificate №58709000637 from 20.05.2009;
- the Database of density contamination of the Belarus Republic settlements with radionuclides cesium, strontium and plutonium as of 1986, the register of certificate №58709000639 from 20.05.2009, National Research Center for Radiation Medicine and Human Ecology;
- the State Registry of Dosimetry data with internal exposure doses calculated based on the results of the WB measurements of residents of the Republic of Belarus for the 2009 – 2012.

Instrumental studies to determine the content of measurements of Cs^{137} in the human body from 1989 – 2012.

We used methods of applied statistics, particularly ANOVA (test Kolmogorov – Smirnov) for the investigation of formation internal dose of individuals depending on personal (demographic) factors. Nonparametric method – the median test Kruskal – Wallis test we used as a test statistic.

Statistical analysis was performed using the software "STATISTICA 8.0" and "MICROSOFT EXCEL 2010".

Results and discussion

Ecological conditions play a significant role in the formation of internal doses, namely soil. Then we selected settlements, which were in identical ecological conditions for correct and adequate analysis and reliability of the results. The soil characteristics determine the aggregative transfer factors of cesium from soil to vegetation, then to the food. The value of aggregative transfer factor ^{137}Cs in basic agricultural products (milk, pork and beef, potatoes, vegetables, forest products) installed on the same product for different soil types Gomel region, differ by almost 2 orders of magnitude.

We used in study Lelchiczkiy, Yelskiy and Narovianskiy settlements of Gomel region (so called Polessky region) with homogeneous soil properties [5]. The sample size was 183187 results of the WB measurements of residents in the 196 settlements. It was sufficient statistical power for each year of the 22-year period since 1989. For correct combination of data on doses, we normalized internal dose by the density of contamination of the respective settlement for each year.

The formation of internal dose depends on personal characteristics such as gender, age, profession, social and economic status. Unfortunately, the State Register contains information only on the age and gender, the study included only these factors influencing the internal dose.

Investigation of the influence the internal dose formation from gender

The analysis of data on internal exposure doses calculated based on the results of the WB measurements revealed significant differences in doses for men and women.

The average value of internal dose for men is higher for the 30% than for women. This difference is due to a higher level of consumption of products by men in general and the level of consumption of locally produced food, because men have a reduced sense of risk compared to women. Figure 1 shows the distribution of internal doses in groups of men and women for the 1990 – 2000 years.

The statistical analysis (Kolmogorov-Smirnov test with a significance level of $p < 0.05$) confirmed a significant difference throughout the study period from the mean internal dose between men and women.

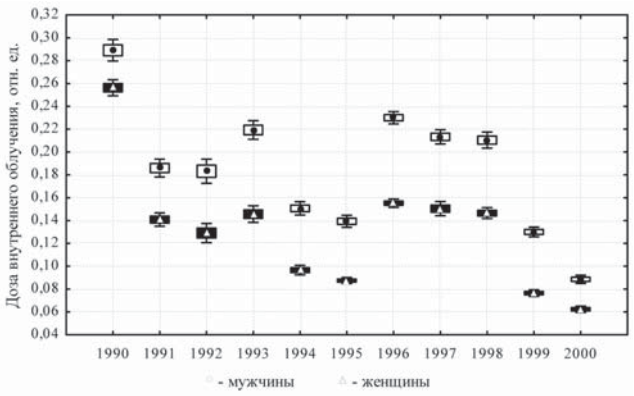

Fig.1. The distribution of internal doses in groups of men and women

Investigation of age dependence of internal dose

The research sample was divided by age groups in steps of 1 year to identify differences in the formation of internal doses by age. We identified four age groups that were statistically significantly different in the mean internal dose using one-way ANOVA (Table 1).

Table 1

Age groups that were statistically significantly different

Age group	Age interval
1	Children (0 – 6 ys)
2	Pupils and students (6 – 18 ys)
3	Adults (18 – 60 ys)
4	Seniors ≥60 ys

The first group included children of preschool age from 0 to 6 years, the second is pupils and students from 7 to 17 years, the third is adults from 18 to 60 years and the fourth – senior of 60 years and older. Significant differences in the mean value in identified of age groups confirmed Kruskal-Wallis test with a significance level of $p < 0.0125$.

Statistical analysis of the distribution of internal dose

Dose distribution in the residents of a certain social structure is the distribution of the population by the radiation dose. It reflects the relation of individuals to radiation hazard factor. This relation creates "food" behavior and consumption level. The relation of individuals to radiation hazard associated with personal characteristics such as gender, age, level of education, health condition, et al.

The personal characteristics of each of the people determined the distribution of internal dose in a population consequently each group of persons, which are homogeneous in demographic characteristics (i.e., the average radiation dose) has the determined location on a curve of dose distribution (fig.2).

Statistical analysis showed that the mean dose identified for four age groups were distributed appropriately on the distribution curve (fig. 2) and the mean value of the radiation dose of each group corresponds to the quartile value.

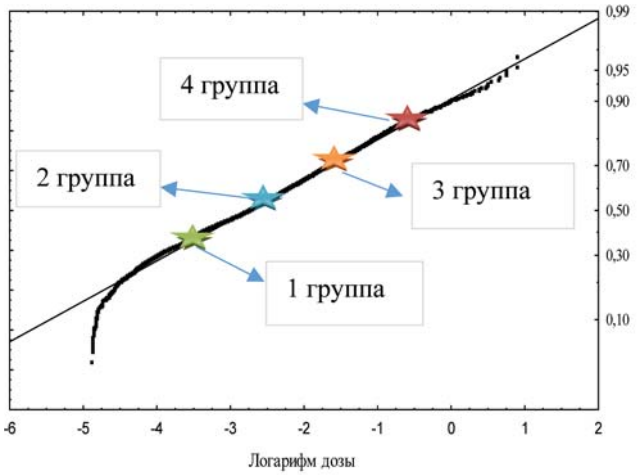

Fig.2. Integral dose distribution with a location of age groups

Table 2 shows the quartile values of dose distribution in each group for each year.

Since the socially conditioned lifestyle that determines the level of consumption radiation products does not change over time, obvious that the location of each age group on the curve dose distribution will remain unchanged. This fact allows us to predict the radiation dose for the certain group by their corresponding quartile.

Table 2

The quartile values of dose distribution in each group for each year

Year	The quartile values of dose distribution in each group, %			
	0-6 ys	7-17 ys	18-59 ys	≥60 ys
1989	41	50	71	79
1990	43	53	68	83
1991	36	47	73	79
1992	20	31	72	79
1993	13	46	68	76
1994	13	38	74	81
1995	28	55	68	76
1996	31	40	66	77
1997	16	33	71	81
1998	21	35	75	80
1999	19	40	65	79
2000	33	47	70	82
Mean	27	43	69	79

The analysis of a formation of internal dose depending on sum of age and gender

Differences in the formation of dose by gender and age allow us to investigate effect of it on the formation of dose in conjunction.

The average internal dose of children under 6 years old do not differ by gender, but in other groups the difference in gender saves. Using the Kruskal-Wallis test with a significance level of $p < 0.05$ was possible to confirm the significant of differences in age groups 2, 3, 4 for men and women.

Similarly, statistical analysis in relation to age groups was defined location on the curve of dose distribution in each age group for men and women, i.e. quartile value distribution of internal dose corresponding to the average dose values of persons in each group (tabl. 3).

Table 3 show us that the percentile values of dose distribution for each age group are significantly different. The average dose of children under 6 corresponds to 26% percentile of dose distribution; for the second group (7-17 ys) the average dose corresponds to 37% and 48% percentiles for men and women, respectively; 57% and 71% percentiles was for adults and seniors, respectively.

The distribution of dose for each age group for men and women during the observation period remained unchanged; it is constant in time. At the same time, the mean dose for men from the third and fourth age groups in the 1990-1994 and 1997 was 76% and 84% percentiles of dose distribution, respectively. And the mean values of internal dose increased for persons 18-59 years old and decrease for persons over 60 years in the 1995-1996 and 1998-2000 years. So, the mean dose correspond to 84% percentile of dose distribution for persons 18-59 years old and 79% percentile – people over 60 years. Such a change in the ratio of dose values in the age groups of males depends on the professional staff, which was not included in this study. For a better understanding of the formation of individual internal dose is advisable to investigate the influence of professional orientation on the formation of dose.

Table 4 show us the percentile values of dose distribution for each age group.

The algorithm for calculating the accumulated personalized internal dose of the persons from the State Register consists of several stages. The first step was to take the data of the WB measurements for each post-accident years considering the change of their residence. The second build a distribution of internal dose by gender for each place of residence and year. And the third, to calculate individualized internal dose by age of each year using the value of the dose distribution from table 4.

Assessment of individualized internal dose for post-accident period was by sum of doses calculated from direct of the WB measurements and dose calculated by the percentile values.

Approbation of the algorithm for calculating the accumulated individualized internal dose of the persons included in the State Register

We conducted calculation of individualized internal doses for 38 randomly selected residents of the district centers and settlements in the Gomel region that in the contamination density of ^{137}Cs from 55 to 6431 kBq/m^2. All of the selected persons have data of the WB measurements.

Comparison of doses calculated by the proposed methodological approach and doses by the WB measurements for the same residents is presented in Table 5.

Individualized internal dose calculated by methodological approaches lies within the confidence interval, which confirm the accuracy of this method; individualized internal doses calculated by the WB measurement has a difference by average for 20%, confirms adequacy of its.

Table 3

The percentile values of internal dose distribution of dose for different age groups

Year	0-6 ys	7-17 ys		18-59 ys		≥60 ys	
	Both	Female	Male	Female	Male	Female	Male
1990	43	47	55	66	69	78	88
1991	36	50	64	67	77	73	83
1992	20	24	39	64	77	74	83
1993	13	42	57	54	75	67	81
1994	13	36	40	62	80	70	87
1995	28	40	47	64	86	70	80
1996	31	36	45	54	84	61	80
1997	16	28	40	61	79	76	84
1998	21	29	42	64	83	71	79
1999	19	35	44	66	86	69	80
2000	33	43	50	64	83	69	76
Mean	26	37	48	57	79	71	82

Table 4

The mean percentile value of dose distribution for each age group in 1989-2012

Age group	The mean percentile value of dose distribution (range of value)			
	0-6 ys	7-17 ys	18-59 ys	≥ 60 ys
Female	26% (21% ÷ 32%)	40% (31% ÷ 49%)	67% (63% ÷ 71%)	78% (74% ÷ 82%)
Male		45% (39% ÷ 51%)	70 (67% ÷ 73%)	79% (75% ÷ 83%)

Table 5

Individualized internal doses, calculating by the WB measurements for the same persons

№	Gender	Year of birth	Settlements (Region)	Soil surface activity, kBq/m^2	Internal dose , mSv/y		
					Calculated	Range of error in mean	By the WB meas-urements
1	2	3	4	5	6	7	8
			1990 y				
1	M	1927	Buda-Koshelevo	1471	0,110	0,105÷0,116	0,069
3	M	1985	Zhitkovichi	382	0,086	0,065÷0,108	0,065
8	M	1966	Glubochica (Checherskij)	1762	0,603	0,579÷0,627	0,527
			1993 y				
12	M	1928	Dobrush	1314	0,195	0,185÷0,205	0,182
15	M	1936	Antonovka (Buda-Koshelevo)	2258	0,114	0,109÷0,119	0,072
18	F	1963	Antonovka (Dobrushskiy)	262	0,122	0,115÷0,129	0,104
19	M	1962	Usoxskaya buda (Dobrushskiy)	55	0,366	0,351÷0,381	0,335
			1998 y				
20	M	1981	Dublin (Braginskiy)	2543	0,237	0,206÷0,268	0,197
21	F	1943	Stezhernoe (Braginskij)	1113	0,192	0,180÷0,204	0,185
22	F	1924	Chemerisy (Braginskij)	710	0,183	0,174÷0,192	0,189

Conclusion

In the result of this study, we established a statistically significant difference of mean values of internal dose by age and sex. We defined the percentiles values corresponding to the average values of internal dose for each age group of men and women. It has the determined location on the curve of dose distribution and that is constant in time. This fact, allows us to calculate the internal dose for each year of post-accident period. It is a methodological basis for the assessment of individualized internal doses of persons exposed to radiation from the Chernobyl accident.

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