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The formation of current internal exposure doses of the Ukrainian Polissia rural population

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This work aimed to identify the specifics and trends of the development of the internal exposure dose (^{137}Cs) of the rural population in Ukrainian Polissia. WBC-measurements were carried out in 2005-2013. Settlements of the Vyshgorod district of Kyiv region and Naroditsky district of the Zhytomyr region were selected for the research. Experimental data were processed using OriginPro 9 and Microsoft Excel 2016. The assumption about several distribution laws for each of the studied data sets was made based on the results of the descriptive statistics of mathematical data samples. The approximation of experimental data revealed an exponential distribution for one sample and attributes of both lognormal and normal distributions for the second one. The problem of exceeding the permissible level of internal exposure doses is relevant mainly for the rural population of Ukrainian Polissia. The novelty of the research is the valuation of objective laws of the formation of current internal exposure doses (by ^{137}Cs) of the Ukrainian Polissia rural population. It was established that in the remote period after the Chornobyl accident an exponential distribution of internal exposure doses of the population is observed in rural settlements of Ukrainian Polissia. This indicates changes in the patterns of the formation of the radiation burden on local residents, which can be explained by the socio-demographic, environmental, and economic factors inherent with each settlement. Due to the nonuniform influence of these factors, the differentiation of settlements on the habitudes of the formation of internal exposure doses of the population takes place. The influence of various factors on the dose formation requires further in-depth study not only within the settlements but even also individual families.
Keywords: rural population, Ukrainian Polissia; internal exposure dose; ^{137}Cs; factors.

Introduction

During recent years, especially after the Fukushima Daiichi Nuclear Power Plant accident, environmental pollution with radionuclides is alarming the global community (Furdychko et al., 2017). It is well known that almost three-quarters of the total dose load of the rural population, caused by the ChNPP accident, consists of ^{137}Cs, a long-lived γ, and β emitter and a potassium congener. It is a common fallout component from disasters at nuclear power plants, such as the Fukushima Daiichi and ChNPP accidents. (Repin et al., 1998; Likhtarov et al., 2015; 'Thirty years after Chornobyl catastrophe: radiological and health effects: National report of Ukraine,' 2016).

^{137}Cs is rapidly incorporated into biosystems and stay down for a long time. Consumption of water and food contaminated with ^{137}Cs leads to its relatively uniform distribution in almost all organs and tissues of the human body (Jelin et al., 2016; Bojko et al., 2020). For people inhabiting the radioactively contaminated lands, the risk of gaining an excessive internal exposure dose with food is inevitable (Omelianets & Khomenko, 2013).

Despite the massive countermeasures retaliated on agricultural lands and in settlements during the post-accident period, the annual internal exposure dose still exceeds 1 mSv/year for a population of 10 settlements of Ukrainian Polissia (Jacob et al., 2001). The results of recent studies (Labunska et al., 2018) convincingly show that the rural population of Ukrainian Polissia, including children, consumes food products with several times the radioactive pollution permissible level. Moreover, the risk of permanent additional internal exposure is relevant only to the rural population. However, the reasons for such a specificity insufficiently studied to date, which complicates the implementation of a balanced development of the agrosphere and sustainable development of the region as a whole. A reliable estimate of both current and accumulated internal exposure doses can be made on the grounds of a careful study of the factors influencing their development.

The share of consumption of certain foods, as well as the level of their radioactive contamination significantly depends on several socioeconomic factors that characterize a particular settlement or region. The results of several studies showed a clear specificity of the rural residents' diet in different parts of Ukrainian Polissia, as well as revealed trends in the diet pattern of the

local population (Kachur et al., 2010). There are significant differences in the internal exposure dose values in rural areas with both high and low densities of radioactive contamination, and they remain steady over time (Vlasova et al., 2014).

The disadvantage of the traditional ecological approach in the analysis of internal exposure doses (Jelin et al., 2016; Jung-Seok Chae et al., 2016; Likhtarev et al., 2000) is that they are based on ^{137}Cs incorporation into the human body mainly from consumption of milk and potatoes, and does not take into account the impact of countermeasures that somewhat reduce the radioactive contamination level of food (milk, potatoes, vegetables, meat).

Also due to the deterioration of socio-economic conditions the share of forest products (mushrooms, berries, game) in the diet of the rural population has increased (Omelianets & Khomenko, 2013; '*Thirty years after Chornobyl catastrophe: radiological and health effects: National report of Ukraine*,' 2016). Current models for calculating the internal exposure dose do not take into account many indirect factors that affect the ^{137}Cs incorporation into the human body and cannot respond flexibly and adequately to socio-economic situation changes or climatic fluctuations. Therefore, it is reasonable to estimate the internal exposure dose based on the results of the WBC-measurements that reveal the actual ^{137}Cs contamination level of the human body from the real diet. Thus, the aim of this work was to identify the specifics and trends of the development of the internal exposure dose (^{137}Cs) of the rural population in Ukrainian Polissia in the remote period after the Chornobyl disaster.

Materials and Methods

The results of WBC-measurements of rural residents of Vyshhorod district (Kyiv Polissia, study site 1, SS1) and Narodytskyi district (Zhytomyr Polissia, study site 2, SS2), Kyiv and Zhytomyr oblasts, respectively (Fig. 1) have been analyzed. These districts were chosen because of their somewhat representative nature for the Ukrainian Polissia countryside, which allows one to consider as many characteristics of the region as possible. SS1 is characterized by a predominance of sod-podzolic soils, a relatively low density of ^{137}Cs surface contamination (48.88 kBq/m^2), relatively large rural settlements (the average population in the village – 1575), and less, compared to SS2, the availability of forest food (average distance to the nearest forest – 13.35 and 1.89 km, respectively). Meanwhile, SS2 is characterized by high ^{137}Cs contamination (230.33 kBq/m^2), small settlements (the average village population – 778), availability of food of forest origin (distance to the nearest forest – 1.89 km), and meadow soils.

Fig. 1. The studied regions of the zone of Ukrainian Polissia: 1 - Kyiv Polissia (SS1), 2 - Zhytomyr Polissia (SS2)

WBC-measurements was assessed with the whole-body gamma spectrometer "Scrinnner-3M" (WBC) during 2005-2013. Calibration was accomplished using two age groups: children and adults. The ^{137}Cs detection error for a child phantom is 13.2% and for an adult one, 12.1%. The lower ^{137}Cs detection limit for 180 sec is $3.7 \cdot 10^2$Bq/body. The detection range of the incorporated radionuclide activity is 0.55-555 kBq. The limit of the permissible relative error of the incorporated ^{137}Cs activity detection in a 3 min exposure does not exceed 30%, P=0.95. Body burdens were measured according to the recommendations for measurements with whole-body counters of the Research Center of Radiation Medicine of the Academy of Medical Sciences of Ukraine (NRCRM) (Recommendations on measurement with whole-body counters during the dosimetric pasportization of residential areas of Ukraine', 1996).

Information on the rural population and the predominant soil types were provided by local administrations. Experimental data were analyzed using OriginPro 9 and Microsoft Excel 2016. The assumptions and conclusions about the probable distribution law of internal exposure doses are based on the descriptive statistics results of WBC-measurements of the SS1 and SS2 populations (2993 measurements in total) and the approximation of distribution types.

Results and Discussion

To obtain a generalized characteristic of the formation of the internal exposure dose of the rural population of the area of interest, we have pre-determined the dose distribution law. Some assumptions and conclusions about the probable distribution law of internal exposure doses can be made using the statistical characteristics of the distribution (arithmetic mean, variance, mean square deviation, median, coefficient of variation, skewness ratio). It should be noted that in the many years after the ChNPP accident, a lognormal distribution of doses of internal radiation was observed in the vast majority of inhabited rural

areas affected by the accident, but recently different results were observed (Raychuk, 2014; Chobotko et al., 2015), in particular, the exponential distribution of the doses.

The proximity of mean square deviation (0,05 mSv/y and 0,21 mSv/y for SS1 and SS2, respectively) and arithmetic mean (0.06 mSv/y and 0.18 mSv/y for SS1 and SS2, respectively), as well as high values of skewness ratio (3.50 and 7.24 for SS1 and SS2, respectively) and coefficient of variation (86.7 % and 117.3 % for SS1 and SS2, respectively) for both data samples are characterized by an exponential distribution. However, the proximity of the absolute median logarithm and the arithmetic mean of the variants logarithms (-1.27 and -1.32 for SS1, -0.86 and -0.82 for SS2, respectively) indicates the presence of lognormal distribution characteristics, and the proximity of the arithmetic mean and median (0.054 mSv/y for SS1, 0.137 mSv/y for SS2) indicates a Gaussian distribution. The approximation of experimental data for these areas with a bin-interval of 0.01 mSv/y (Fig. 2) confirmed the hypothesis of the exponential distribution for SS1 and the Gaussian one for SS2. However, when changing the discrete interval (increasing the interval to 0.05 mSv/y) (Fig. 3), the set of data for SS2 revealed a lognormal distribution. Thus, the hypothesis of the exponential distribution law is accepted for SS1 by Pearson's test. Stability in specific conditions is the peculiarity of such processes. Settlements of SS2, and those similar to them, have socio-economic conditions that are the same — i.e., the inhabitants' diet and food contamination with radionuclides, which is reduced mainly due to radionuclide decay, are permanent or little variable. Taking into account the relative immutability of socio-demographic and economic characteristics of Northern Polissia countryside of Ukraine, there are some reasons to expect that the exponential distribution law of the individual internal exposure dose of the population affected by the Chornobyl accident many years later will be inherent for many rural settlements of the region.
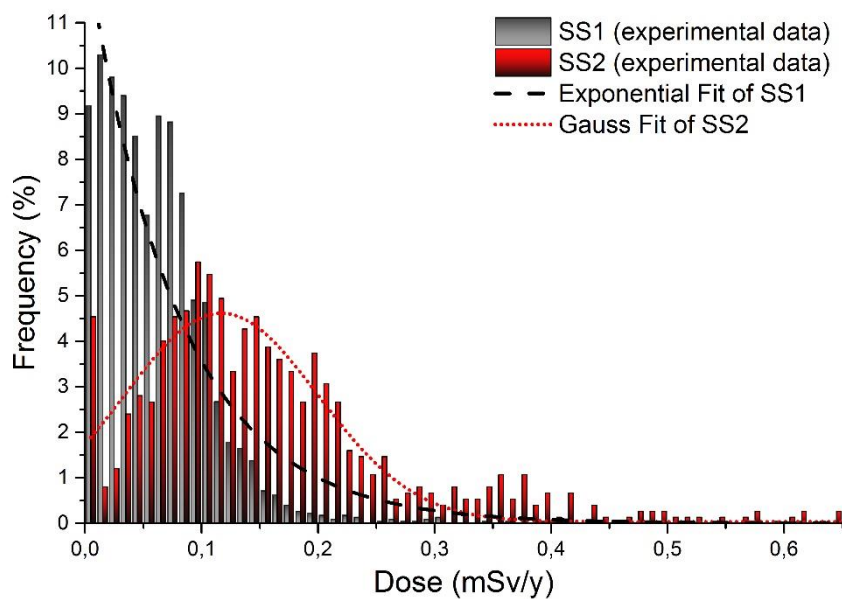

Fig. 2. Graphical interpretation of the distribution law of the internal exposure dose of the rural population SS1 and SS2 (discrete interval of 0.01 mSv/y)

The internal radiation dose for the SS2 population has signs of both lognormal distribution and the Gaussian one. Therefore, it can be assumed that the statistical aggregate is formed as a result of the effect of a significant number of independent (or slightly dependent) random variables, none of which is predominant. However, some of the factors that influence the formation of this aggregate can prevail (for instance, some foods) under certain conditions.

Consequently, both Study Sites are characterized by a specific set of various socio-economic and environmental factors, which determine the peculiarities of the internal exposure dose of the rural population and should be taken into account when assessing and predicting the body burden.

This approach is consistent with the theory (Skryabin & Hille, 1998), which states that the characteristics of a person or group of people with similar socio-economic behavior determine certain features of the development of the internal exposure dose of the population. Thus, the body burden is another, complex characteristic of a group of people (family, settlement, or district). Therefore, the next appropriate step is to determine the probable most important factors that affect the development of the internal exposure dose. The characteristics of the settlement are, in a way, a set of characteristics of its inhabitants (Vlasova, 2014). Therefore, it is logical to take into account such personal characteristics as an education level, occupation, age, gender, etc. Among the general features of the settlement, we can distinguish the radioactive contamination level of the territory, the predominant soil type, the distance to the nearest district center and forest, the size of the settlement, etc. (table 1). These indicators were pre-selected in terms of their availability and the probable impact on internal exposure doses of the population. Personal characteristics, such as an education level, affect a person's awareness and attitude to radioactive contamination, which considerably determines consumer behavior. While the contamination level of the territory, soil type, distance to the forest, and the nearest district center determine the possibility (probability) for residents of radioactively contaminated regions to get food with a certain level of radionuclide contamination.

Table1. General ecological and social characteristics of the studied settlements

Settlement	Dose, mSv/y	Population	Forest area, %*	Education level**	Density of ¹³⁷Cs surface contamination, kBq/m²	Predominant soil type ***	Distance to the nearest local center, km	Distance to the nearest forest, km
					Zhytomyr Polissia			
Bazar	0,09	526	7	1	235	4	23,7	5,2
Zakusyly	0,14	295	5	3	253	5	10,0	2,2
Kalynivka	0,08	30	19	2	243	3	20,9	2,3
Narodychi	0,17	2996	5	3	240	5	0	2,2
Radcha	0,21	265	63	3	59	3	22,1	0,3
Rozsokhivske	0,08	275	0	1	25	1	26,9	4,3
Selets	0,08	398	35	1	63	1	36,9	1,1
					Kyiv Polissia			
Andriivka	0,17	109	53	1	83	1	40,0	0,5
Bodenky	0,03	428	7	1	32	7	32,1	3,0
Bohdany	0,14	93	43	1	72	1	68,5	0,2
Vakhivka	0,12	326	77	1	108	6	13,1	0,7
Vyshhorod	0,03	27825	21	1	24	2	0	1,5
Vyshcha Dubechnia	0,02	831	36	1	43	7	20,1	0,6
Volodymyrivka	0,13	242	69	1	42	6	16,8	0,2
Voropaivka	0,02	896	52	1	29	7	24,6	0,7
Dymer	0,07	5786	5	1	33	2	25,0	2,6
Fedorivka	0,11	275	46	1	56	6	15,9	0,3
Huta Katiuzhanska	0,09	128	51	2	41	6	19,5	0,3
Hlibivka	0,09	984	11	1	27	2	25,5	0,7
Khotianivka	0,32	53	95	2	86	1	19,0	0
Kozarovychi	0,09	1804	0	1	40	6	20,9	5,8
Lebedivka	0,04	1257	42	1	37	3	11,2	0,5
Lisovychi	0,07	287	18	1	45	1	27,3	2,1
Liubymivka	0,10	390	19	1	53	4	25,6	1,0
Lytvynivka	0,07	1350	23	1	31	1	23,3	1,0
Nyzhcha Dubechnia	0,02	1330	44	1	30	3	15,4	1,3
Novosilky	0,01	850	34	1	24	7	10,7	0,6
Pirnove	0,02	670	17	3	46	7	23,1	0,9
Pyliava	0,13	42	21	2	95	1	31,2	0,3
Rudnia-Dymerska	0,22	18	43	1	74	1	24,3	0,7
Rykhta	0,23	69	68	2	392	3	9,8	0,6
Rykun	0,28	779	25	2	200	5	3,6	0,7
Rytni	0,02	343	21	1	31	5	14,0	0,7
Sukholuchchia	0,13	211	10	1	59	4	37,9	3,5
Suvyd	0,16	126	66	1	69	4	29,1	0,5
Sychivka	0,10	401	52	1	48	1	27,1	2,0
Tolokun	0,02	982	8	1	30	7	8,8	0,6
Yasnohorodka	0,11	585	31	1	42	4	29,2	2,1
Zhukyn	0,04	1117	19	1	31	7	36,2	1,6

Note: 3 – * percentage of the forest area, within a radius of 3 km from the settlement; **the most common one (1 – no education or junior secondary education, 2 – senior secondary education, 3 – vocational school or college); ***1 – sod-cryptopodzolic sandy and clay-sandy, 2 – sod-mesopodzolic clay-sandy, 3 – sod-cryptopodzolic sandy and clay-sandy clayed, 4 – sod-mesopodzolic clay-sandy clayed, 5 – estuary, 6 – peat-bog soil and lowland peat, 7 – sod primary-clayed sandy and clay-sandy.
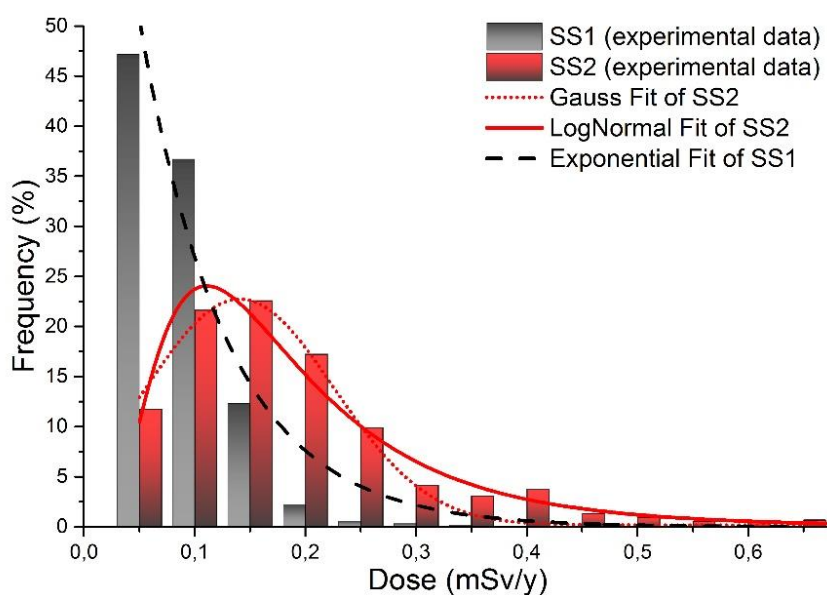

Fig. 3. Graphical interpretation of the distribution law of the internal exposure dose of the rural population SS1 and SS2 (discrete interval of 0.05 mSv/y)

Thus, we can assume that each settlement is characterized by a certain set of direct and indirect factors that affect the development of the exposure internal dose, and hence its typical average value. For example, residents of small settlements in forested areas, far from district centers (Khotianivka, Rudnia-Dymerska, Rykhta), are more likely to consume food of forest origin, which is known to be one of the most polluted. While the residents of relatively large settlements located not far from the district centers (Lebedivka, Nyzhcha Dubechnia, Tolokun) will be able to consume food of non-local origin. Therefore, the probability of receiving relatively high internal exposure doses is lower than for the first group. However, the average values of the internal exposure dose can be explained so clearly not for all settlements. The obtained preliminary results need to be further studied to analyze the factors influencing the development of the internal exposure dose of the population of Ukrainian Polissia in the remote period after the Chornobyl accident in more detail. Undoubtedly, a comprehensive socio-demographic, economic and environmental analysis of the region is appropriate, at least in terms of individual settlements. To identify the impact of personal characteristics on the formation of consumer behavior and body burden for the population, a complex analysis of factors in terms of individual families is needed.

Conclusion

The problem of exceeding the permissible level of internal exposure doses is relevant mainly for the rural population of Ukrainian Polissia. The novelty of the research is the assessment of the regularities of the formation of the modern internal exposure dose (^{137}Cs) for the rural population of Ukrainian Polissia. The vast majority of rural settlements exposed to radioactive contamination are characterized by a lognormal distribution of internal exposure doses.
In the remote period after the Chornobyl accident in the rural settlements of Ukrainian Polissya features of exponential distribution of internal exposure doses of the population have been established. This indicates changes in the patterns of forming of the body burden for rural residents, which can be explained by socio-demographic, environmental, and economic factors inherent in each settlement. Due to the heterogeneity of the influence of these factors, there is a differentiation of settlements according to the special characteristics of the development of internal exposure doses of the population. The influence of various factors on the dose forming requires further in-depth study in terms of not just settlements, but also individual families.

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