Estimation of Thyroid Doses from Inhalation of ^{131}I for Population of Contaminated Regions of Belarus

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Abstract

Based on the relationships between ^{131}I and ^{137}Cs content in soil samples and the data on ^{137}Cs contamination of settlements, the ^{131}I deposition density $S_n(^{131}\mathrm{I})$ was estimated for the settlements located in the eastern and the southern areas of Belarus (1,079 and 316 settlements, respectively). The results show that the 90% interval of the $S_n(^{131}\mathrm{I})$ quantity is about 500 - 2,300 kBq/m^2 and 700 - 3,500 kBq/m^2 for the eastern and the southern area, respectively. Using assessments of $S_n(^{131}\mathrm{I})$, thyroid doses from inhalation of ^{131}I were evaluated with taking into account the period and character of radioactive deposition in various parts of the areas. According to the results, the thyroid doses for adult population of the eastern and the southern areas vary from 3 to 80 mSv and from 40 to 370 mSv, respectively, while the median doses are about 20 and 130 mSv, for the eastern and the southern area, respectively. Uncertainties in the calculation of thyroid doses, due to the procedure applied, were discussed.

Introduction

The data on cancer incidence rates accumulated in Belarus after the Chernobyl accident [1] show a statistically significant increase in the number of thyroid cancer, especially among the children. According to [1], in period 1991-2000 standardized incidence rate for thyroid cancer increased from 3.6 up to 9.2 per 100 000 population (about 2.6 times). The fast increase of thyroid cancer cases evoked interest to the problem of thyroid dose assessment. The individual thyroid dose estimations in Belarus were derived primarily from the results of direct ^{131}I thyroid measurements carried out in May and June of 1986 [2]. Note that ^{131}I is the most important radionuclide that caused serious thyroid exposures in the affected areas in the first few weeks following the accident. Thyroid cancers risk assessments obtained in the framework of the ICRP recommendations by using the doses derived from thyroid measurements show an excess of observed thyroid cancer cases over the expected number [3]. In this connection the assessment of thyroid doses from inhalation and ingestion of ^{131}I is of interest for a prediction of radiological consequences by the Chernobyl accident.

The measurements of ^{131}I activity in thyroid of people and determination of ^{131}I concentration in food stuffs and air were accomplished only in part of the contaminated territory. In order to evaluate the thyroid doses for the population of those regions where no monitoring was performed, a procedure based on reconstruction of ^{131}I deposition density can be applied. Using the ^{131}I-^{137}Cs relation obtained in [4] and the data on ^{137}Cs contamination of settlements (see [5]) the ^{131}I deposition density was evaluated in the present paper for settlements placed in the eastern and the southern areas of Belarus (see Fig.1). Based on these assessments thyroid doses from inhalation intake of ^{131}I were obtained for adult population.

Reconstruction of ^{131}I Deposition Density

The estimates of ^{131}I deposition density were calculated on the basis of the relationship between ^{131}I and ^{137}Cs activity concentration in soil samples taken in the contaminated regions under consideration [4].

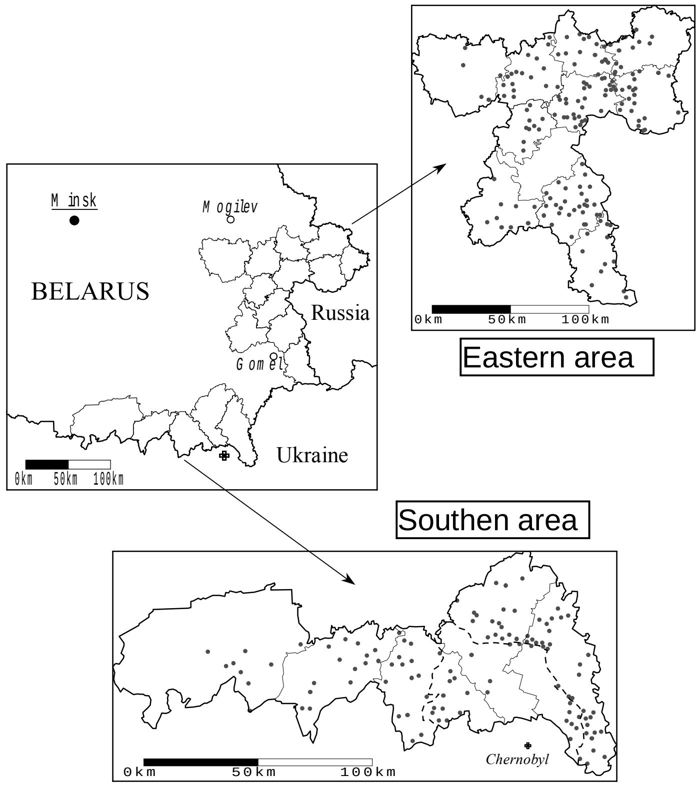

Fig. 1. Areas under investigation.

The points show settlements where soil samples were taken. Dot line within the southern area shows the boundary of the Polesskyi state radioecological nursery (the zone of evacuation).

Note that the relationship had been deduced in [4] with taking into account the contribution of ^{137}Cs global fallout that is about 2.2 kBq/m^2. The regression function describing the data for the contaminated regions was written in form:

$$^{131}\mathrm{I} = \mathrm{A_k} \cdot [^{137}\mathrm{Cs}]^{\mathrm{B_k}} \qquad (1)$$

where the radionuclides activity in soil is expressed on May 10, 1986, and the parameters A_k and B_k are characterized by the following values: A_1=33.8 kBq/m^2, B_1=0.63 and A_2=69.4 kBq/m^2, B_2=0.59 for the eastern (k=1) and the southern (k=2) area, respectively. Starting from the expression (1), the mean density of ^{131}I deposition $S_n(^{131}\mathrm{I})$ in the territory of the n-th settlement situated in the studied areas was obtained by using the formula:

$$S_n(^{131}\mathrm{I}) = \mathrm{A_k} \cdot [S_n(^{137}\mathrm{Cs})]^{\mathrm{B_k}} \qquad (2)$$

where $S_n(^{137}\mathrm{Cs})$ is the level of settlement contamination with ^{137}Cs. Empirical values of $S_n(^{137}\mathrm{Cs})$ expressed on May 10, 1986 were taken from [5].

It should be noted that the settlements situated in the territory of the zone of evacuation (see Fig.1) were not included in the present calculations of $S_n(^{131}\mathrm{I})$. Population of the evacuation zone was removed during the first week of May 1986 when the radioactive release still continued. Dose estimation for removed inhabitants needs special consideration taking into account a day of evacuation.

The distributions of values $S_n(^{131}\mathrm{I})$ calculated for 1,079 and 316 settlements situated in the eastern and the southern areas, respectively, are presented in Fig.2 in comparison with the distributions of empirical data on $S_n(^{137}\mathrm{Cs})$. According to the results, the values of $S_n(^{137}\mathrm{Cs})$ and $S_n(^{131}\mathrm{I})$ are described by a lognormal distribution:

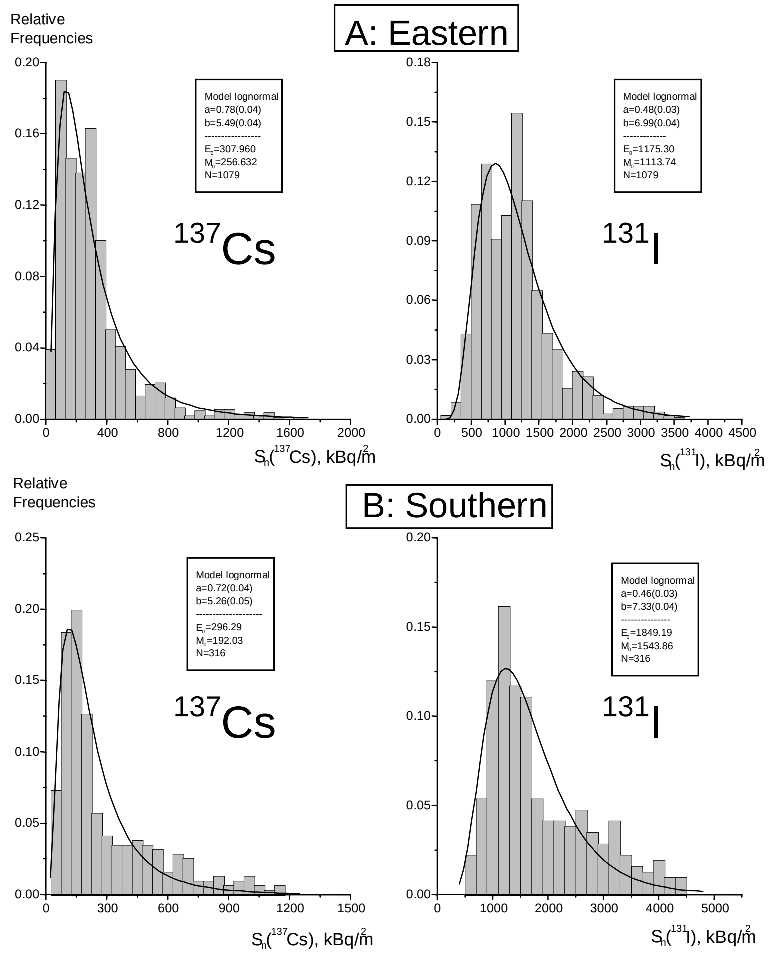

Fig. 2. Distributions of ^{137}Cs contamination level and the estimated ^{131}I deposition density for settlements situated in the eastern (A) and the southern (B) areas of Belarus.

$$f(x) = \frac{\exp[-(\ln x - b)^2 / 2a^2]}{2\pi a x}. \qquad (3)$$

The parameter a in (3) characterizing skewness of the distribution is defined as $a = [2(\ln E - \ln M)]^{1/2}$, where E is the average, and $M = \exp(b)$ is the median of the distribution. The analysis of the distribution parameters shows that the median value of $S_n(^{137}\mathrm{Cs})$ obtained for the settlements situated in the eastern area is about 35% larger than in case of the southern area. At the same time the variation $\mathrm{V} = \sigma/E = (e^{a^2} - 1)^{1/2}$ of values $S_n(^{137}\mathrm{Cs})$ takes the close values for the studied areas. Note that in accordance with [6] the quantity of variation of radionuclide deposition density reflects the heterogeneity of Chernobyl fallout.

According to the distribution parameters derived (see Fig.2), the median value of $S_n(^{131}\mathrm{I})$ obtained for the settlements situated in the southern area is about one third larger than in case of the eastern area. The 90% interval of the $S_n(^{131}\mathrm{I})$ quantity is about 500 - 2,300 kBq/m^2 and 700 - 3,500 kBq/m^2 for the eastern and the southern area, respectively. The comparison of the distribution characteristics given in Fig.2 shows that the ratio of median values R_{med} = med[$S_n(^{131}\mathrm{I})$]/med[$S_n(^{137}\mathrm{Cs})$] for the eastern area is about 1.8 times smaller than for the southern area. It should be stressed that the present values of $S_n(^{131}\mathrm{I})$

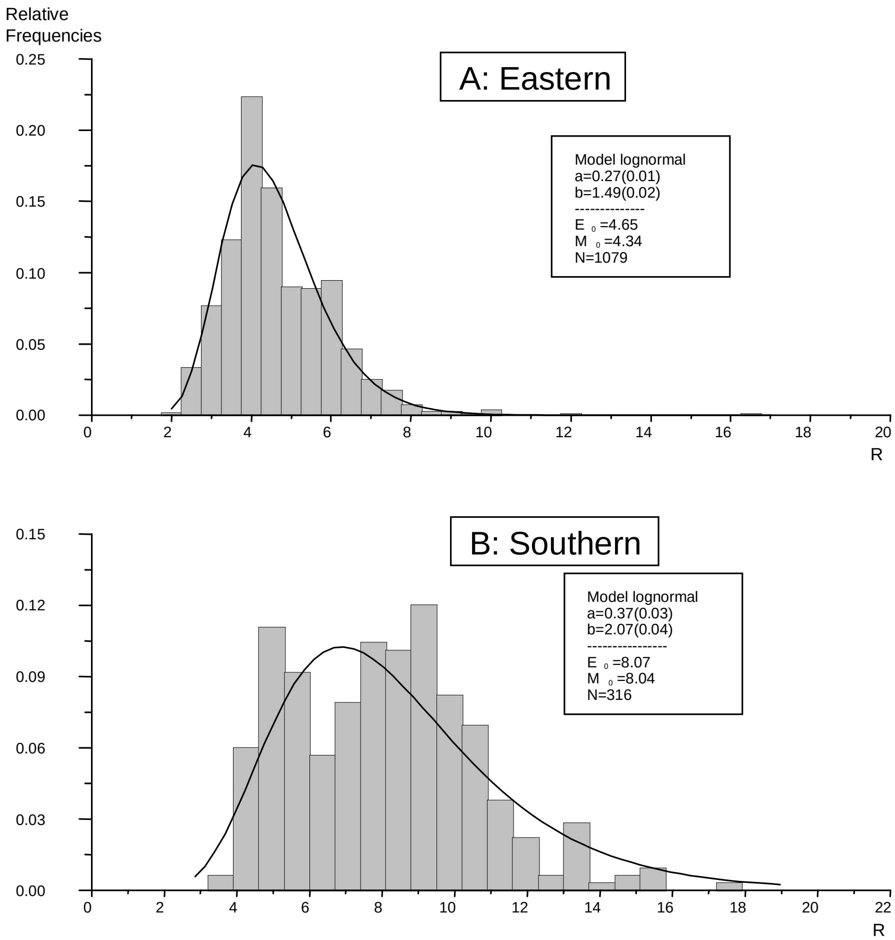

Fig. 3. Values of the ratio R=S_n(^{131}I)/S_n(^{137}Cs) obtained for settlements situated in the eastern (A) and the southern (B) areas.

were obtained by using the radionuclides activities expressed on May 10, 1986.

The distributions of the isotope ratio $R = S_n(^{131}\mathrm{I})/S_n(^{137}\mathrm{Cs})$ are given in Fig.3. According to the results, about 90% of ratio values obtained for the eastern area range between 3 and 7. In case of the southern area the quantity *R* takes a value mainly in the interval 4 < *R* < 13. The estimations of *R* agree with the isolines of the isotope ratio ^{131}I/^{137}Cs in the Chernobyl fallout at Belarus territory (see [7]). The observed difference between isotope ratio ^{131}I/^{137}Cs in deposition of Chernobyl radionuclides can be caused by several factors, in particular, various gaseous and aerosol iodine fractions in radioactive discharges of the Chernobyl NPP as well as the deference of wash-out rate between aerosol and gaseous iodine (see [8]).

Evaluation of Thyroid Dose from Inhalation of ^{131}I

Thyroid doses from inhalation intake of ^{131}I were estimated in a framework of the approach described in [9]. The formula used for calculation of the inhalation dose *D* was written as

$$D = d \cdot A = d \cdot f \cdot C \cdot r \cdot t \, , \qquad (4)$$

where d is committed effective or organ dose equivalent per unit intake via inhalation, A is activity intake over the time period t, C is the mean activity concentration of radionuclide in air, r is inhalation rate, and f is the shielding factor of inhabitants. The values of quantities d and r for different age groups of population are presented in [10] and [11], respectively. Following to [9] it was conservatively assumed for the purposes of dose assessment that $f = 1$.

The radionuclide concentration in air C was estimated on the basis of the data on deposition density S, deposition velocity v, and the time period of deposition T

$$C = \frac{S}{v \cdot T}. \quad (5)$$

According to the data presented in [12], in general the contamination of air in the southern area continued for nine days. About 90% of ^{131}I activity fell out during the period 8:00 April 26 - 8:00 April 29, 1986. The territory of the eastern area was contaminated by radioactive fallout mainly in two days, namely 8:00 April 27 - 8:00 April 29. The fraction of ^{131}I activity which fell out during the pointed period on the territories of different administrative districts situated in the eastern area range from 75% to 95%. The contamination of the eastern area persisted until May 10, 1986.

Data from [12] show different characteristics of radioactive deposition among the areas under consideration. The territory of the southern area was contaminated by dry deposition, whereas wet deposition prevailed in the eastern area. The contribution of wet deposition to the overall contamination of territory of several districts in the eastern area was about 75%. The velocity values of dry (v_d = 0.4 cm/s) and wet (v_w = 3.0 cm/s) deposition of ^{131}I used in the present work were taken from [13].

The expression for evaluation of settlement contamination with ^{131}I is written as

$$S_n(^{131}\mathrm{I}) = \sum_{t_m} S_n(t_m) \cdot k(t_m), \quad (6)$$

where $S_n(^{131}\mathrm{I})$ is the density of ^{131}I deposition at the territory of the n-th settlement on May 10, 1986, $k(t_m) = \exp(-\Delta t_m / \tau)$, $\Delta t_m = t_f - t_m$ is the period from the final day (t_f) of deposition (i.e. May 10, 1986) and the m-th day of deposition, and τ is half-life time of ^{131}I. In order to use the data on daily deposition of ^{131}I the quantity $S_n(t_m)$ was expressed

$$S_n(t_m) = a(t_m) \cdot \sum_{t_m} S_n(t_m), \quad (7)$$

where $a(t_m)$ is daily fraction of summarized deposition activity of ^{131}I. The values of $a(t_m)$ characterizes daily variation of ^{131}I deposition in the period April 26 - May 10, 1986 (see [14]). Taking into account expressions (6) and (7) the relationship between $S_n(^{131}\mathrm{I})$ and $\sum_{t_m} S_n(t_m)$ is written as

$$\sum_{t_m} S_n(t_m) = S_n(^{131}\mathrm{I}) / [\sum a(t_m) \cdot k(t_m)]. \quad (8)$$

On the basis of Equations (4) - (8), the expression for estimation of thyroid dose from daily (t = T = 1 day) inhalation of ^{131}I was defined as

$$D_n(t_m) = d \cdot f \cdot r \cdot h \cdot S_n(^{131}\mathrm{I}) / v(t_m), \quad (9)$$

where $h = a(t_m)/[\sum a(t_m) \cdot k(t_m)]$. Distributions of $S_n(^{131}\mathrm{I})$ values used for dose calculations are given in Fig.2. Starting from equation (9), the doses from inhalation during the main period of radioactive deposition Δt = April 26 - May 10, 1986 were estimated as a sum of doses from daily inhalation intake of ^{131}I:

$$D_n(\Delta t) = \sum_{t_m} D_n(t_m). \quad (10)$$

Results and Discussion

The calculation results show (see Fig.4) that thyroid dose equivalent for adult population of the areas under investigation varies from a few to a few hundreds of mSv. Dose values obtained for 95% of the settlements situated in the eastern and southern the areas are smaller than 45 and 300 mSv, respectively. The maximal dose is about 80 mSv in the eastern area and about 370 mSv in the southern area. The median value characterizing the dose distribution obtained for the southern area is about 6 times larger than in case of the eastern area. The computations of thyroid dose for children show that the dose assessments obtained for children of 10 years old are 1.8 times larger than the results for adult population. It should be emphasized that present dose assessments correspond to conservative (largest) value of the factor *f*. Note that thyroid doses from inhalation intake of ^{131}I are smaller then doses from ^{131}I intake with foodstuff. According to [12], ^{131}I intake with cow milk evaluated for adult residents of settlements located in Gomel district (southern area in our case) are higher than 500 mSv.

It should be emphasized that the present dose estimation based on the relationship between ^{131}I and ^{137}Cs activities in soil does not takes into account local features of ^{131}I deposition and inhalation. As a result the spatial distributions of the reconstructed ^{131}I deposition densities $S_n(^{131}\mathrm{I})$ and the thyroid doses D_n are similar to the distribution of the ^{137}Cs contamination levels of the settlements $S_n(^{137}\mathrm{Cs})$ in the area of investigation. In particular, two maxima revealed in the statistical distribution of dose D_n calculated for population of the eastern area may be caused by the peculiarities of location of settlements in this area (see Fig.2 and Fig.4).

Based on the expressions (9) the behavior of the normalized thyroid dose $D_n^0 = D_n / S_n(^{137}\mathrm{Cs})$ can be modeled by the power function, which is simply deduced using the isotope ratio $R = S_n(^{131}\mathrm{I})/S_n(^{137}\mathrm{Cs})$:

$$D_n^0 \propto [S_n(^{137}\mathrm{Cs})]^{C_k} \quad (11)$$

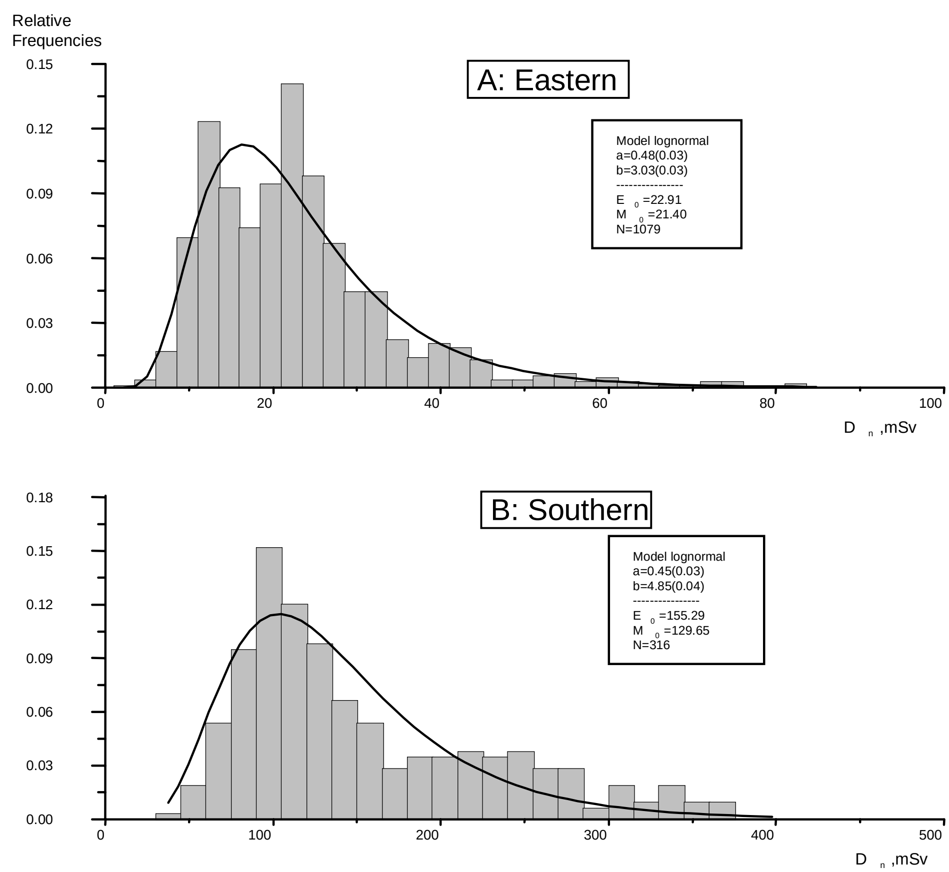

Fig. 4. Distributions of thyroid dose D_n from inhalation of ^{131}I calculated for adult population of the settlements located in the eastern (A) and the southern (B) areas.

where C_k = B_k − 1 < 0 (see (1)). According to equation (11), the normalized dose D_n^0 decrease with increasing of ^{137}Cs contamination density. Equation (11) can partly explains the decreasing trend in the normalized mean values of thyroid dose measured for population of 70 settlements with the increase of the ^{137}Cs contamination level [2].

The present estimats of thyroid dose from inhalation of ^{131}I are associated with uncertainties arising from different sources. One of them is the ^{131}I deposition velocity v depending on type of deposition (wet or dry). No data about the quantity v in the areas of investigation are available. For this reason the velocity values v_w = 3.0 cm/s and v_d = 0.4 cm/s derived in [13] for radioactive deposition were used for the present calculation. The value 3.0 cm/s agrees with estimation 2.6 cm/s (the difference is about 15%) obtained for velocity of ^{131}I wet deposition in the town Obninsk situated on the territory of Kaluga region (Russia) bordering upon the eastern area under investigation (see [15]). The velocity value for dry deposition (0.4 cm/s) is two times larger than estimation 0.2 cm/s derived in the measurements carried out in the Research Center of Seibersdorf (Eastern Austria) in April-July 1986 [8]. Considering that the radionuclide concentration in air is directly related with deposition velocity, the value of deposition velocity would be the important source of uncertainty in dose estimation, in particular for the southern area where dry deposition was dominant.

The next source of uncertainties is dose dependence on the period of ^{131}I deposition. In this connection it should be noted that the previous thyroid dose estimation for population of the eastern area (see [16]) was carried out in proposal of constant daily wet deposition of ^{131}I during April 28 - May 2, 1986. The comparison of the dose distribution given in Fig. 4 with data from [16] shows that dose values obtained in [16] in average are about 20% smaller than the present estimations. The similar uncertainties in dose estimation can be caused by errors in the parameters A_k and B_k characterizing the relationship between ^{131}I and ^{137}Cs deposition densities, or errors in the level of settlements contamination with ^{137}Cs (see [16]). Note that despite the uncertainties mentioned above, the assessment of ^{131}I deposition density and thyroid exposure based on the procedure described seems reasonable taking into consideration the lack of empirical data on ^{131}I content in air and soil.

Conclusion

Using the relationships between ^{131}I and ^{137}Cs activity concentration in soil samples and the data on the level of settlements contamination with ^{137}Cs, the ^{131}I deposition density $S_n(^{131}I)$ was evaluated for the settlements situated in the territory of the eastern and the southern areas of Belarus. The results show that the median values of $S_n(^{131}I)$ obtained for settlements located in the eastern and the southern area are about 1.1 and 1.5 MBq/m^2, respectively.

Based on the assessments of $S_n(^{131}I)$ thyroid doses from inhalation of ^{131}I were calculated for adult population of the studied areas. The results show that thyroid doses D_n for population of the eastern area change in region $3 < D_n < 80$ mSv. In case of the southern areas the dose values vary from 40 to 370 mSv. The median doses are about 20 and 130 mSv, for population of the eastern and the southern area, respectively. The observed difference between doses is caused mainly by different character of ^{131}I deposition in the studied areas.

The values of thyroid dose normalized to the level of settlement contamination with ^{137}Cs tend to decrease with increasing ^{137}Cs deposition density. This tendency in behavior of the normalized dose reflects the non-linear relationship derived between ^{131}I and ^{137}Cs concentration in soil.

The results of the present estimation of ^{131}I deposition density and thyroid doses from inhalation of ^{131}I will be included in wide-scale computations of thyroid dose for population of the contaminated regions of Belarus.

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