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Methodology of Thyroid Dose Reconstruction for Population of Russia after the Chernobyl Accident

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INTRODUCTION

The Chernobyl accident has provoked radioactive contamination upon such extensive territories that the monitoring of short-lived iodine isotopes and estimation of their influence upon people were performed with a delay or not completely. For solving the problem of dose estimation for thyroid exposure with iodine radionuclides among the population of contaminated territories, it was necessary to analyze retrospectively the existing data and to develop a model of the thyroid dose reconstruction. The reconstruction procedure for the average for a settlement thyroid dose in Russians has been worked out basing on the following data received in May-June 1986:

- 44 thousand measurements of I-131 content in the thyroid of inhabitants;
- 2000 gamma-spectrometric measurements of milk samples in Tula region;
- about 3500 measurements of total beta-activity in milk samples from Bryansk, Kaluga and Orel regions;
- over 100 radiochemical analysis of milk samples for I and Cs radionuclides' content;
- about 14000 thousand polls of inhabitants and local administration authorities upon the regime of behavior, milk consumption, cattle pasture dates and countermeasures in May 1986;
- the data of Roshydromet upon Cs-137 contamination of soil in settlements.

The individual dose estimations by direct measurements of I-131 in the thyroid have been accepted as the basis for dose reconstruction.. In the absence of direct measurements, to reconstruct the thyroid dose, the measurement results of ^{131}I concentration in milk of local produce and empirical dependencies between the dose in thyroid of inhabitants and the ^{131}I concentration in milk were used.

For those settlements where only the level of soil contamination with long-lived ^{137}Cs radionuclide can be used, the empirical dependence of ^{131}I concentration in milk on ^{137}Cs in soil was used for recalculation in the dependence of the average dose on the ^{137}Cs soil contamination density in the settlement.

According to the analysis of meteorological conditions for transfer of radioactive substances released from the destroyed reactor, contamination of the central part of Russia took place due to depositions from one radioactive cloud (1-3). 10 Russian regions were subjected to radioactive contamination, beginning from the Bryansk region in the west of Russia (a part of the "Bryansk – Belorussia spot"), and to the east from it. Radionuclide ratios in depositions on these territories were approximately the same. Therefore, for them we may use the methods for assessment of thyroid doses in inhabitants obtained on the basis of the data of radiation monitoring in 1986 in four most contaminated regions.

In the report, we present substantiation of the technique for reconstruction of doses in thyroid of inhabitants of Russia due to the Chernobyl accident, approved by theAll-Russia Scientific Commission on Radiation Protection as the official method for assessment of radioiodine isotopes exposure consequences after the Chernobyl accident.

DETERMINATION OF131I ACTIVITY IN THYROID ON THE BASIS OF DIRECT MEASUREMENTS

Broad-scale measurements of ^{131}I content in thyroid of population of contaminated areas were begun on 14-15 May, 1986. The measurements were performed in regional hospitals with diagnostic facilities GTRM-01T or "GAMMA", and in the contaminated settlements with portable radiometric devices SRP-68-01. The diagnostic equipment had a detector with a crystal NaI(Tl) (∅ 40 x 40 mm), lead collimator. Measurements at diagnostic device were made at the distance between neck and detector from 13 to 22 cm. The device SRP-68-01 was equipped with a scintillation detector (∅ 30 x 20 mm), without collimator and with threshold of energy about 25 keV (4-7).

Measurements in the Bryansk oncological clinic with the "Gamma" device were performed in two detector positions– perpendicularly to the neck and above the thigh (4, 5). The measurements done with the SRP-68-01 device in the Bryansk and Kaluga regions were performed in three variants of geometry of measurements: close to the neck and thigh, or to the neck and "liver" (detector perpendicularly to the body from the front), or measurement of the neck only (6-8). About six thousand measurements were made in Russia in May-June 1986 with radiodiagnostic equipment and forty thousand measurements with SRP-68-01 (4-8).

^{131}I activity in thyroid has been calculated by the formulas:

$$G = K(u)\cdot[(P_n - a_n(u)\cdot P_f) - b_{n/th}(u)\cdot(P_{th} - a_{th}(u)\cdot P_f)], \quad \text{kBq}, \qquad (1)$$

$$G = K(u)\cdot[(P_n - a_n(u)\cdot P_f) - b_{n/liv}(u)\cdot(P_{liv} - a_{liv}(u)\cdot P_f)],\quad \text{kBq}, \tag{2}$$

where: P_n , cps or μR/h - count-rate or dose rate over the neck;

P_{th} , P_{liv} , cps or μR/h - count-rate or dose rate over the thigh or liver correspondingly;

P_f , cps or μR/h - count-rate or dose rate in the point of measurement without man

K(u), kBq/(μR/h), -calibration factor. Calibration of radiodiagnostic devices was performed in accordance with the technique for diagnostic survey. Average calibration factors for SRP-68-01 depending on age are presented in table 1 (9-11) ;

$a_n(u)$, $a_{th}(u)$, $a_{liv}(u)$, rel. un., - coefficient for shielding background by a human body, it laid between 0,9 and 1,0 for neck and thigh, and between 0,7 and 0,9 for "liver" depending on the age and used equipment.

$b_{n/th}(u)$, $b_{n/liv}(u)$, rel. un., - the factor that takes into account geometric relations for measurements of extrathuroidal gamma radiation in positions at the neck and thigh or liver. For the SRP-68-01 device, the average values of these parameters were: $b_{n/th}(u) = 0.85 \pm 0.05$; $b_{n/liv}(u) = 0.70 \pm 0.05$. At measurements by the collimated detector in the Bryansk oncologic clinic $b_{n/th}(u) = 1.15 \pm 0.05$ for children under 7 years, and $b_{n/th}(u) = 1$ for al the rest of ages.

TABLE 1. Calibration factor *K(u)* for SRP-68-01 radiometer for measurements of ^{131}I in thyroid of man and correction factor g(u) in dependence on age *u*

u, complete years	*K(u)*, kBq/(μR/hour)	*g(u)*, rel. un.	*u*, complete years	*K(u)*, kBq/(μR/hour)	*g(u)*, rel. un.
0	0.11	0.60	10	0.13	0.71
1	0.11	0.60	11	0.14	0.74
2	0.11	0.61	12	0.14	0.76
3	0.11	0.62	13	0.15	0.79
4	0.12	0.63	14	0.15	0.82
5	0.12	0.64	15	0.16	0.85
6	0.12	0.65	16	0.17	0.90
7	0.12	0.67	17	0.18	0.94
8	0.13	0.68	>17	0.19	1.00
9	0.13	0.70			

When calibration factors *K(u)* were present for separate devices, they were used for calculation of ^{131}I activity according to formulas (1), (2). In this case, the value of *K(u)* for adults was corrected for other age groups by multiplication by the factor g(u) from Table 1.

Contribution of radiation of caesium radionuclides distributed in the body, and possible surface contamination of a person, in the case of single thyroid measurements by means of SRP-68-01, could be estimated due to the presence of double measurements in part of persons at each day of the survey (8). All double measurements were used for determination of individual “illumination” factors X_i :

$$X_i = \frac{P^i{}_{liv} - a_{liv}\cdot P_f}{P^i{}_n - a_n\cdot P_f}. \tag{3}$$

All individual values X_i were averaged for each day of measurement and for three age groups: 0-7; 8-17 and above 18 years. Processing of all double measurements of persons in the Bryansk and Kaluga regions during the period of measurements from 21 May till 7 June, 1986, showed linear dependence of the illumination factor ***X(t)*** on the day of measurement and the absence of statistically significant differences between the age groups. Fig. 1 presents the plot of ***X(t)*** dependence.

The values obtained for the factor *X(t)* were later used for calculation of I-131 activity in thyroid, in the case of a single measurement in detector position by the neck:

$$G = K(u)\cdot\left[P_n - a_n(u)\cdot P_f\right]\cdot\left[1 - b_{n/liv}(u)\cdot X(t)\right],\ \textbf{kBq}, \tag{4}$$

where X(t) was determined by the empirical function:

$$X(t) = -0.34 + 0.031\cdot t, \tag{5}$$

Where t - is the day after the radioactive contamination of the area

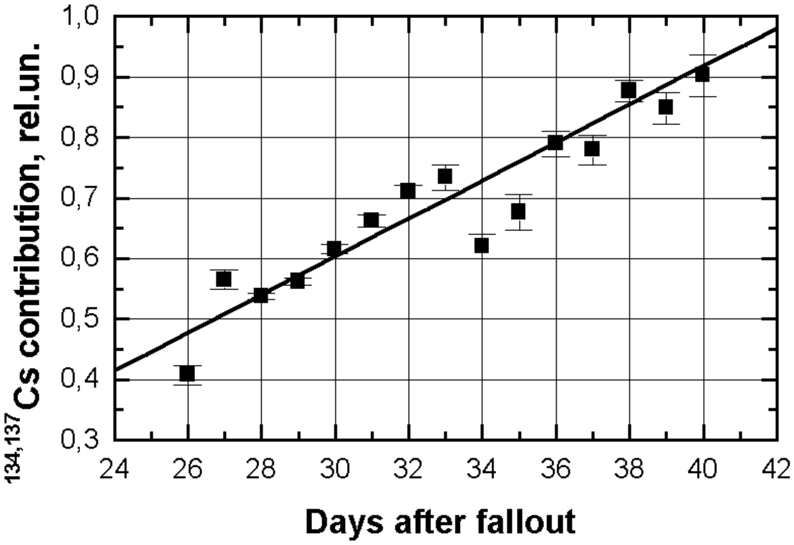

Fig. 1. Illumination factor ***X(t)*** depending on time after fall-out

MODEL OF IODINE-131 INTAKE IN THE BODY OF INHABITANTS

For the purposes of thyroid dose reconstruction after the Chernobyl accident, three main sources of iodine-131 intake in thyroid are taken into account: inhalation of the radionuclide during the passage of the radioactive cloud; consumption of contaminated milk; other intake sources, of which the main are consumption of leaf vegetables and other contaminated food products, inhalation during the period after the passage of the radioactive cloud etc. The value of radioiodine intake in the body of inhabitants is strongly influenced by the date of the beginning of dairy cattle pasturing and of termination of local milk consumption. With consideration for these main factors, we developed the model of iodine-131 intake in the body of man in the post-accidental period. The parameters of this model were based upon the analysis of the radiation monitoring data.

Fig. 2 shows the general form of the ^{131}I intake function in the body of inhabitants of age u with inhaled air i_{inh} and with food i_{ing}. Equations (6-7) give its mathematical description:

$$i_{inh}(t, u, \sigma_{137}) = i_0 \cdot f_1(u) \cdot f_2(\sigma_{137}),\ 0 < t < t_1; \tag{6}$$

$$i_{ing}(t) = \begin{cases} i_0 \cdot f_3 \cdot e^{-\ln 2 \cdot t / T_{ec}}, & 0 < t \le t_2; \\ i_0 \cdot (f_3 \cdot e^{-\ln 2 \cdot t / T_{ec}} + (1 - f_3) \cdot (e^{-\ln 2 \cdot (t - t_2) / T_{tc}} - e^{-\ln 2 \cdot (t - t_2) / T_1})), & t_2 < t \le t_3; \\ i_0 \cdot f_4 \cdot (f_3 \cdot e^{-\ln 2 \cdot t / T_{ec}} + (1 - f_3) \cdot (e^{-\ln 2 \cdot (t - t_2) / T_{ec}} - e^{-\ln 2 \cdot (t - t_2) / T_1})), & t_3 < t; \end{cases} \tag{7}$$

where: i_0 , kBq/day, - the constant value;
t , days, - the time after the beginning of radioactive depositions in the region;
t_1 , days, - the duration of inhalation from the radioactive cloud; it is assumed equal to 1 day;
t_2 , days, - the time of beginning of pasturing cows from private farms.

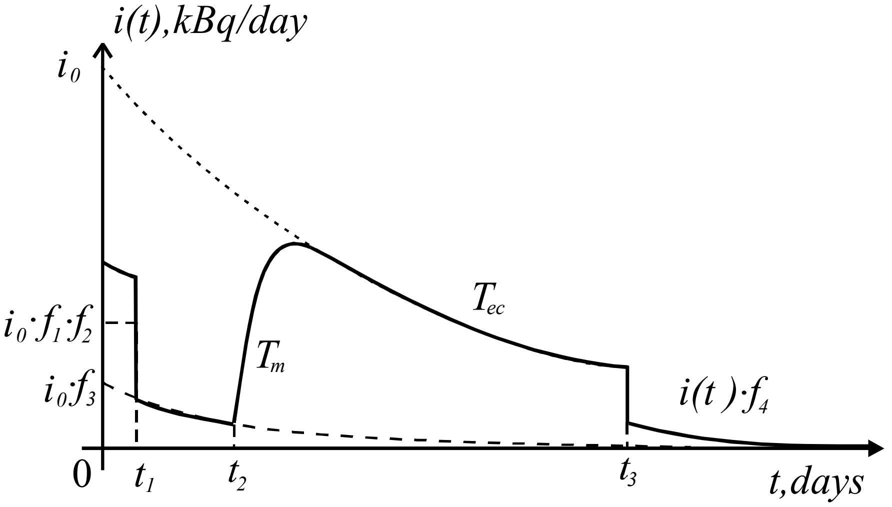

Fig.2. Model of ^{131}I intake into inhabitants of Russia after the Chernobyl accident

$f_1(u)$ is the factor that takes into account the relation between daily consumption of milk and the volume of air inhaled during a day by children and teenagers of age *u*, as compared with adults, see Table 2;

TABLE 2. Values of factor $f_1(u)$, rel. un., in formula (7) for persons of different age groups.

Age, years	< 1	1 - 2	2 - 7	7 - 12	12 - 17	> 17
$f_1(u)$, rel. un., (villages)	0.1	0.2	0.4	0.6	0.9	1.0
$f_1(u)$, rel. un., (towns)	0.1	0.2	0.4	0.8	1.5	1.8

$f_2(\sigma_{137})$ - the factor that takes into account the relation between inhalation and “milk” ways of intake in formation of the thyroid dose in dependence on the density of soil contamination with ^{137}Cs. The following considerations were taken into account for estimation its value.

At dry fallout of radionuclides their deposition on soil is proportional to the time of the passage of the radioactive cloud across the given area and to the rate of the radionuclides deposition. The average deposition rate of iodine radionuclides was 0.8 cm/s (12, 13). Using this value for the rate of dry deposition and the average value of iodine-131 retention by grass (14), we calculated the relation between intake of the iodine radionuclides to a human body with the air and with food products at dry deposition and average duration of the passage of the radioactive cloud across the settlement equal to 1 day. For adult rural inhabitants it was $f_2(\sigma_{137}) = 0.15$. For children at the age *u* this ratio differed by $f_1(u)$ times.

In the area, where contamination took place by wet washing out, the relative role of inhalation decreases with the increase of the level of soil contamination by $f_2(\sigma_{137})$ times. We assumed that the inhalation component stays approximately the same for the whole area of the passage of the radioactive cloud. The basic soil contamination and the interception of radioiodine by vegetation depended on the amount of precipitations (14). The level of soil contamination, at which wet depositions began to influence, was assessed on the basis of the data of measurements of ^{131}I concentration in milk. At the level of about 50 kBq, the point of inflection was observed in the curve of dependence of ^{131}I concentration in milk on the soil contamination density with ^{137}Cs. We assume this value as the upper limit of the contamination, which was attributed only to dry depositions. Taking into account the non-linear character of the dependence of radioiodine interception by vegetation (14), the ratio between the inhalation and ingestion ways of ^{131}I intake in the body of adult inhabitants in dependence on the soil contamination density with ^{137}Cs is described by the expression:

$f_2(\sigma_{137}) = 0{,}15$ at $\sigma_{137} \leq 100$ kBq/sq.m;
$f_2(\sigma_{137}) = 2{,}0 \cdot \sigma_{137}^{-0{,}56}$ at $\sigma_{137} > 100$ kBq/sq.m; (8)

f_3 , rel. un., is the factor that assesses ^{131}I intake in the body of inhabitants with leaf vegetables, other surface contaminated food products, and with milk during the time of cattle stabling. The total contribution of these processes in the thyroid dose was determined with the following considerations.

- The analysis of relations between individual thyroid doses from iodine-131 exposure after the Chernobyl accident and the milk consumption showed that, depending on the age, 10-20 % of the dose was connected with “non-milk” intake (15).

- Data on the dynamics of ^{131}I deposition after the Chernobyl release (12) showed that after the passage of the maximum of depositions their intensity decreased approximately by an order of magnitude in a day, and then gradually decreased during May 1986. The presence of detectable depositions implied inhalation intake to people. These processes were connected with the surface contamination of grass and soil. So modelling this source of ^{131}I intake in the body of man the rate of this process was assumed to be equal to the rate of grass decontamination with the amplitude equal to 0.1 of the value of inhalation intake during the first day.
- If we assume that the iodine-131 concentration in milk was equal to one conventional unit, that the transfer factor from the daily food ration of a cow to 1 l of milk was equal to 0.003-0.01 (16, 17), and that during a day a cow ate 40-50 kg of grass (16, 17), then the iodine concentration in grass was equal to 2.5-8.3 conv. un. Correspondingly, leaf vegetables had approximately the same ^{131}I concentration. Assuming the average consumption by an adult person of 20 g/day of leaf vegetables and 0.5 l/day of milk, the factor of culinary losses for vegetables of 0.6, we obtain the ratio of daily intakes of iodine-131 with vegetables and milk equal to approximately 0.1-0.2. For children, this ratio was less because of less consumption of vegetables.

Generalising the above considerations, the average assessment $f_3 = 0.15$ for all discussed processes seems the most acceptable one.

f_4, rel. un., is the factor of decrease of ^{131}I intake in the body due to cessation of consumption of local milk and other local food products in May, 1986. For persons, with respect to whom the fact of cessation of milk consumption was determined, the f_4 value was assumed equal to 0.15 rel. un., and for the rest persons – 1.0 rel. un.

For the inhabitants of a settlement, for which there were no individual data on cessation of milk consumption, we assumed: $f_4 = 1 - 0,85\cdot f_5$,
where f_5, rel. un., is the part of inhabitants in the settlement, who stopped to consume milk, according to the data of the polls in 1986 and 1987.

T_1 = 1,5 days is the half-period of milk decontamination after single intake of iodine-131 in the body of a cow (17);

T_{ec}, days, is the period of decrease of ^{131}I concentration in milk of cows pastured on the contaminated area. It was assumed equal to 4.2 days on the basis of data of monitoring in Russia after the Chernobyl accident;

The data about the dates of beginning of pasturing cows were obtained as a result of individual polls of inhabitants in 1987 and collection of data in collective farms in 1995-1997. For those districts, where no polls were performed, the dates of the beginning of pasturing were assessed on the basis of the analysis of meteorological data on daily average temperatures, the amount of precipitations and the mass of growing grass in April-May, 1986.

The unknown parameter i_0 in the intake function (6-7) is determined from the equation:

$$G(t_M) = \int_0^{t_M} (i_{inh}(\tau)\cdot 0.66\cdot R_{th}(t_M-\tau;u) + i_{ing}(\tau)\cdot R_{th}(t_M-\tau;u))d\tau, \quad \text{kBq}, \qquad (9)$$

where: $G(t_M)$, kBq, is the ^{131}I activity in thyroid as of the moment of the measurement t_M;
$i_{inh}(t)$, $i_{ing}(t)$ are determined by equations (6) and (7), respectively;

$R_{th}(t;u) = 0,3\cdot e^{-\frac{\ln 2\cdot t}{T_{th}(u)}}$, rel. un., is the ^{131}I retention function in thyroid after its intake with food (18). The values of the iodine excretion half-period from thyroid $T_{th}(u)$ for persons of different ages were taken from the ICRP Publication 56 (19);

$0.66\cdot R_{th}(t;u)$, rel. un., is the ^{131}I retention function in thyroid after intake with inhaled air of the mixture of equal concentrations in the air of ^{131}I in the forms of elementary iodine, methyliodide and aerosol fraction with AMAD equal to 1 μm, and fast absorption in the inhalational tract (17, 19).

After determination of the parameter i_0, kBq/day of the intake function, equation (9) is used for calculation of the total intake in the body of an individual with inhaled air, $I_{inh,}$ and food, I_{ing},, kBq, as the integral over time of the corresponding function (rate) of intake $i(t)$, kBq/day:

$$I_{inh} = \int_0^{\infty} i_{inh}(\tau)\cdot d\tau \qquad (10)$$

$$I_{ing} = \int_0^{\infty} i_{ing}(\tau)\cdot d\tau \qquad (11)$$

The expected individual absorbed dose in thyroid $D_{th}(u)$ for a person of age u is calculated according to the formula:

$$D_{th}(u) = I_{inh}\cdot d_{inh}(u) + I_{ing}\cdot d_{ing}(u), \ \text{mGy} \qquad (12)$$

where: $d_{inh}(u)$, $d_{ing}(u)$, mGy/kBq, are the dose factors for ^{131}I intake in the body of persons of age u by inhalation and ingestion ways, respectively (18-19).

AVERAGE AND STANDARD DOSE FOR A SETTLEMENT

The average absorbed thyroid dose (AATD) is determined for six age groups of inhabitants in each settlement of the Russian Federation, for which the ^{137}Cs soil contamination density in 1986 is known, or ^{131}I concentration in milk of local produce in May, 1986 is known. Age boundaries for the groups were determined in the same way, as it was done in the modern ICRP publications (17-19) for the dose factors: **1)** – under 1 year, .**2)** - 1-2 years, **3)** - 3-7 years, **4)** - 8-12 years, **5)** - 13-17 years; and **6)** – adults above 17 years. The AATD for the j-th (j = 1, .., 6) age group of inhabitants of a settlement D_{th}^{j}, mGy, is calculated as the arithmetic mean for the results of determination of individual doses $D_{th}(u_i)$, mGy, in persons of the j-th group on the basis of individual measurements of thyroid in May-June, 1986.

The ^{131}I dose absorbed in human thyroid depends on the activity incorporated in the body, on the thyroid mass and on iodine metabolism in the body of a person. All these parameters, including the intake in the body, connected with consumption of milk and the rate of breathing, vary with age. In each settlement children of younger age received the highest doses, and adults – the lowest ones. Age dependencies of the doses averaged over settlements differ for rural and urban inhabitants (4, 5, 9). The dose in children under 1 year in towns is by 15-16 times higher, and in a village – by 7-8 times higher than the average dose in the group of adults.

The dose absorbed in thyroid depended on ^{131}I concentration in milk and its variation with time, on milk consumption rate, individual age, and countermeasures. To find out regularities of connection of the thyroid dose with other parameters of radioactive contamination, the dose values were standardised with respect to the time of beginning of pasturing dairy cattle, to age, and to countermeasures. For this, the standard dose, D_{th}^{st}, was introduced. It was calculated as the arithmetic mean of all individual doses recalculated to one "reference" age - 3 year, with the use of the dependencies of the average dose on age for urban and rural inhabitants, in the assumption that dairy cattle was pastured by the moment of radioactive depositions (t_2=0 in formula (7)), and that the countermeasures were not applied ($t_3 = \infty$).

Empirical dependencies of the standard dose on ^{131}I concentration in milk and on soil contamination with ^{137}Cs radionuclide were obtained on the basis of results of radiation monitoring in the four most contaminated regions of Russia. They were used for reconstruction of the standard thyroid dose in settlements, where no direct measurements in thyroid were done in 1986.

RECONSTRUCTION OF THE AVERAGE THYROID DOSE ON THE BASIS OF 131I CONCENTRATION IN MILK OF LOCAL PRODUCE

In the Bryansk, Orel and Kaluga regions in May-June, 1986, the analysis of samples of milk of local produce was performed for the total beta activity. In the Tula region, spectrometric measurements of milk samples by means of one-channel spectrometer in the energy channel of registration of gamma radiation of ^{131}I (150-450 keV) were performed.

At the same time, in the Bryansk region 47 radiochemical analyses were done for ^{131}I and 53 analyses – for the total cesium (^{134}Cs+^{136}Cs +^{137}Cs) in milk, of them 24 analyses were done on the same milk samples. Due to these investigations, it became possible to separate the part attributed to ^{131}I from the measurement results of total beta activity. According to the results of the radiochemical analyses, the half-time of variation of the ratio of ^{131}I to the total cesium in milk with time equalled to 5.8 days. Applying the obtained ratio to each measurement of the total beta activity, we determined ^{131}I concentration in milk for each measurement date. Then, on the basis of the dynamics of the specific ^{131}I concentration in milk (iodine-131 concentration in milk divided by the soil contamination density with cesium-137), we determined the effective half-time of milk decontamination from ^{131}I .

The effective half-time of the ^{131}I concentration decreasing according to results of independent measurements of the total beta activity of milk in the three regions was equal to 3.9, 4.0, and 4.2 days, which practically coincided with the value for the half-time obtained with spectrometric measurements in the Tula region, 4.2 days (Table 3).

Using these values of the half-time, all results of measurements in milk in May, 1986, were recalculated to one reference date, 08.05.86. The reference ^{131}I concentration in milk C^{r}_{m}, kBq/l, produced and/or consumed in the settlement was determined as the arithmetic mean value of concentration $C_m(t_i)$ in milk samples corrected on 08.05.86 (whose number should not be less than 5 in a village or 10 in a town or in urban-type community) according to the formula:

$$C_m^r = \frac{1}{n}\cdot\sum_{i=1}^{n} C_m(t_i)\cdot e^{-\frac{\ln 2\cdot(t_i-t_r)}{T_m}}$$, kBq/l, (13)

where: t_i is the time of sampling of the *i*-th milk sample (days) after the beginning of radioactive depositions;

t_r is the reference time equal to 10 days after the beginning of radioactive depositions on the territory of the Bryansk region and corresponding to the reference date of 8 May, 1986;

T_m is the half-time of of ^{131}I decreasing in milk, assumed equal to 4.2 days.

Statistically valid relation between the reference ^{131}I concentration in milk with the ^{137}Cs contamination density in soil, σ_{137}, was found from the data of milk monitoring in four regions. The corresponding regression equations had, on the whole, non-linear character, but at the soil contamination density with ^{137}Cs, above 37 kBq/m^2 (1 Ci/km^2) and below 700 kBq/m^2 (≈20 Ci/km^2) it was satisfactorily described by a linear function. , where no measurements of radionuclides content in milk were performed during May 1986 The reference concentration in milk, C^r_m, for rural settlements in four most contaminated regions of Russia could be assessed by the equation (14) with the parameters from the table 3:

$$C_m^r = c + d\cdot\sigma_{137}$$, kBq/l, (14)

TABLE 3. Half-time of milk decontamination T_m , parameters of regression equation (14) and correlation factors *r* for the four regions of Russia

Region	T_m, days	c, kBq/l	d, m^2/l	r
Bryansk	4.2±0.3	10.0±1.1	0.090±0.008	0.95
Orel	3.9±0.2	2.5±0.7	0.085±0.010	0.95
Kaluga	4.0±0.3	4.0±0.3	0.092±0.004	0.85
Tula	4.2±0.2	4.9±0.9	0.077±0.013	0.99

Good agreement of the approximating functions and their numeric parameters was found for independent sets of measurements from four concerned regions. The obtained results give the basis to perform processing of all data of milk measurements in four regions jointly. Fig. 3 gives the plot of this dependence, and the regression equation has the form:

$$C^r_m = (4.5\pm0.9) + (0.090\pm0.004)\cdot\sigma_{137},\quad R=0.94 \qquad (15)$$

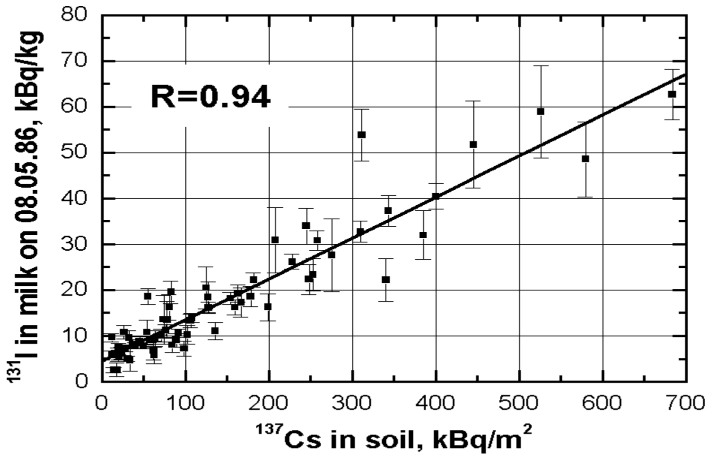

Fig.3. Reference ^{131}I concentration in milk on 08.05.1986 depending on soil contamination with ^{137}Cs. Data from Bryansk, Tula, Kaluga, Orel regions.

The dependence (15) can be applied not only in the four considered regions, but in the adjacent areas of Russia contaminated with depositions of radioactive products of the Chernobyl accident with similar radionuclide composition **at the ^{137}Cs soil contamination density in 1986 above 37 kBq/m^2 (≈1 Ci/km^2) and below 700 kBq/m^2 (≈20 Ci/km^2).**

According to the data of radiation monitoring in four regions of Russia, the average standard thyroid dose in inhabitants of a settlement D_{th}^{st} was connected with the reference ^{131}I concentration in milk C^{r}_{m}, kBq/l by the linear regression equation:

$$D_{th}^{st} = b \cdot C_{m}^{r}, \quad \text{mGy} \qquad (16)$$

where: b = (10,5 ±0,7) mGy·l/kBq for villages, towns and cties

Fig. 4 presents this dependence for rural settlements. Each point presents the measurement results for one settlement Data for 43 settlements in the Kaluga region, 17 settlements in the Bryansk region and 5 settlements in the Tula region were used for plotting this dependence.

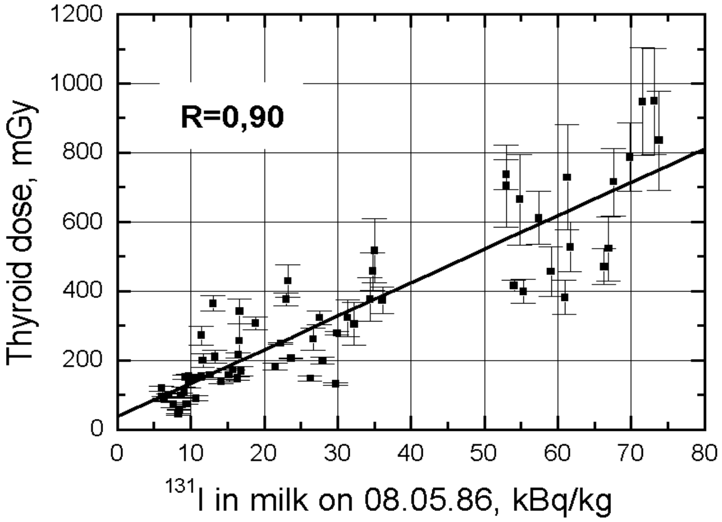

Fig. 4. Dependence of standard thyroid dose in rural settlements on reference ^{131}I concentration in milk on 08.05.1986 according data from Bryansk, Kalyga, Tula regions.

Regression equation (16) with the corresponding parameters was used for assessment of the average standard dose D_{th}^{st} in thyroid of inhabitants of rural and urban settlements, where in May and June 1986 the measurements of ^{131}I content in thyroid were not performed or their number and/or quality was unsatisfactory, and where measurements of ^{131}I concentration in milk were performed, and the estimated reference ^{131}I concentration in milk C^{r}_{m} did not exceed 100 kBq/l.

CALCULATION OF THE AVERAGE THYROID DOSE ON THE BASIS OF THE 137CS SOIL CONTAMINATION DENSITY

For the most contaminated villages of Western districts of the Bryansk region, where the monitoring data on ^{131}I concentration in milk samples were insufficient for the dose reconstruction, it is recommended to use the empirical dependence of the standard dose in the settlement obtained on the basis of the data of measurements of ^{131}I content in thyroid of inhabitants, on the level of area contamination with ^{137}Cs. 43 settlements with the soil contamination density with cesium-137 above 0.4 MBq/m^2 (≈10 Ci/km^2), with more than30 direct measurements of inhabitants were used for construction of the regression.. It is described by the equation:

$$D_{th}^{st} = g + h \cdot \sigma_{137}, \ \text{mGy}, \qquad (17)$$

where: g = (374 ± 65) mGy;

h = (0,44 ± 0,05) mGy·m^2/kBq.

σ_{137} is measured in kBq/m^2.

Equation (17) is valid for assessment of the standard dose D_{th}^{st} for inhabitants of rural settlements of the western districts of the Bryansk region only at the soil contamination density with ^{137}Cs in 1986 above 400 kBq/m^2 (≈10 Ci/km^2).

For reconstruction of the standard thyroid dose in inhabitants of four regions the parameters of equation (17) were assessed by substitution of equation (14) with parameters from Table 3 to equation (16):

Table 4. Parameters of regression equation (18) for areas with ^{137}Cs soil contamination density above 37 kBq/m^2 and under 500 kBq/m^{2}r

Region	g, mGy	h, mGy·m^2/kBq
Bryansk	105±14	0.95±0.10
Orel	26±8	0.89±0.11
Tula and Kaluga	42±4	0.97±0.06

Regression equation (17) with parameters from Table 4 is directly used for assessment of the standard thyroid dose in inhabitants of rural settlements in the four indicated regions at the soil contamination density with ^{137}Cs in 1986 above 37 kBq/m^2 and below 500 kBq/m^2, where in May-June 1986 no measurements of ^{131}I content in thyroid of inhabitants and in milk samples were performed or their number and/or quality was not satisfactory.

After determination of the average standard dose D_{th}^{st} on the basis of the results of individual radiometry of thyroid of inhabitants of a settlement in May-June 1986 or by means of equation (16), (17), the average thyroid dose in the *j*-th age group of inhabitants of a settlement D_{th}^{j} is calculated with the formula:

$$D_{th}^{j} = \frac{D_{th}^{st}}{p_j} \cdot \frac{D_{1j}}{D_{1j}^{st}}, \text{ mGy,} \qquad (18)$$

where: values p_j for the j-th age group are taken from the age dependencies of the dose for towns and villages;
D_{1j} , mGy, is the dose in persons of the *j*-th age group calculated with (12) for the intake rate i_0=1 kBq/day and actual conditions of the given settlement;
D_{1j}^{st} , mGy, is the dose in persons of the *j*-th age group calculated with (12) for the intake rate i_0=1 kBq/day and standard conditions: pasturing dairy cattle by the moment of the radioactive depositions ($t_2 = 0$) and the absence of countermeasures ($t_3 = \infty$).

The found average dose value for the given age group of inhabitants of a settlement is assumed as the reference value, with respect to which actual individual doses are distributed in accordance with the lognormal law. The personal assessment must be specified, if the volume and type (goat, cow) of consumed milk or the time of staying of the concrete person in the settlement considerably differed from the corresponding conditions assumed for the settlement as the typical ones. When reliable information about such individual specific features are present, the average point assessment should be individualised by introducing corrections that reflect the difference of individual parameters from the assumed average values for the settlement.

The technique for reconstruction of the thyroid dose presented in the report was used for assessment of average doses in settlements of the central part of Russia that suffered from radioactive depositions after the Chernobyl accident.

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