Influence of dynamics of ^{131}I fallout due to the ChNPP accident on value of absorbed doses in thyroid for population of Bryansk and Kaluga regions of Russia

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Proposed is a model for estimating absorbed doses in the thyroid using the time-dependencies between the volume concentration in the surface air layer and density of ^{131}I fallout on soil obtained by modelling atmospheric transport of ^{131}I. Using of Bryansk and Kaluga regions of the Russian Federation as an example it has been shown that the dynamics of ^{131}I fallout on the territories contaminated after the ChNPP accident has a significant effect on estimation of absorbed doses in the thyroid in inhabitants of these regions.

Individual absorbed doses in the thyroid of inhabitants of some settlements in Bryansk and Kaluga regions contaminated due to the ChNPP accident have been estimated from the results of direct radiometry of thyroid carried out in May-June 1986. Verification and comparison of data of thyroid radiometry for contaminated territories of Bryansk and Kaluga regions has also been conducted. The relation between estimated ^{131}I activities and absorbed doses in the thyroid of inhabitants of these regions reflects differences in character and intensity of radioactive contamination of the territories under consideration. The results indicate that adjustment of the values is required and this, as a rule, lowers estimated activities of incorporated ^{131}I. The average value of this correction is about 0.1 μCi and it varies depending on the age of a person under examination.

The average absorbed doses in the thyroid for different age groups of people living in the contaminated points is higher by a factor of 5 to 15 in the Bryansk region than in the Kaluga region. The paper presents an analysis of the relationship between the estimated absorbed doses in the thyroid and the ^{137}Cs contamination density. It has been shown that the statistical hypothesis concerning the linear relationship between the average thyroid dose and ^{137}Cs contamination density seems to be unjustified for the residents of the contaminated areas of the Kaluga and Bryansk regions.

Introduction

The most significant of possible negative consequences for health of the population living on the Chernobyl contaminated areas is internal irradiation of the thyroid gland with iodine radionuclides. Russian National Medical and Dosimetric Registry (RNMDR) contains few data on individual internal absorbed doses for thyroid. That is why it is so important to estimate and reconstruct individualized absorbed thyroid doses for persons included in RNMDR based on all available data about environmental contamination and also data of individual radiometry of thyroid.

As a result of the Chernobyl accident a large amount of iodine radionuclides was released into the atmosphere which led to the contamination of extended areas in May-June 1986. The characteristic feature of the Chernobyl accident was that the contamination was prolonged because of a series of sequential releases of radioactive materials up to the end of May 1986 [1]. This was, among other things, supported by measurements of dynamics of ^{131}I and ^{132}Te deposited on collectors in the locations of meteostations on the territory of the former USSR [2]. However, there is still no clear and comprehensive understanding of how the contamination with the aerosol and gaseous forms of iodine was being developed over the whole territory of CIS. Using different approaches and based on the results of gamma spectrometry of soil samples, maps of ^{131}I depositions on soil in CIS and Russia have been generated (see [3] and [4]). These data, however, do not account for the dynamics of contamination. Works [5, 6] contain results of modelling atmospheric transport of radionuclides over different distances, but they can not be used directly for estimating absorbed thyroid doses.

In work [7] using a statistical model [8] for turbulence diffusion of radioactive material in the atmosphere an attempt was made to reconstruct dynamics of ^{131}I, ^{132}I and ^{133}I depositions on the territory of Russia. This work does not claim to give a definitive solution for reconstruction of the dynamics of contamination of CIS territory with iodine radionuclides. Nevertheless, the results obtained in this work can become a basis for estimating absorbed thyroid doses, taking by way of an example two regions of Russia - Bryansk and Kaluga in which radiological measurements of thyroid were conducted on a mass scale in May-June 1986. In this case, there is no need for assumptions concerning the function of ^{131}I release to the environment, as is usually done in all published works on estimation of absorbed thyroid doses.

A large-scale dosimetric examination of the population of Russia was undertaken in Bryansk [9] and Kaluga [10] regions in May-June 1986. In [11] absorbed thyroid doses were estimated in the assumption of instantaneous release of ^{131}I on the territory of Kaluga region (conventionally 1 May 1986). In work [9] it is assumed that the function of ^{131}I intake by man is constant during 15 days after contamination and later it decreases exponentially. The guidelines [12] include methods for estimating absorbed thyroid doses under different assumptions concerning the character of iodine intake by thyroid.

In this work we use the function of ^{131}I inflow on soil and near surface air layer estimated from the atmospheric transport model with allowance for “local effective precipitation” [7], which correlate the model function with the measurements of ^{131}I and reconstruction data.

The absorbed thyroid dose from exposure to iodine radionuclides is primarily determined by contamination of the environment and foods. The contamination of foods and diet govern the rate of intake of radionuclides by man. The absorbed dose is also influenced by parameters of iodine metabolism in the organism. These parameters are well understood, but they mostly apply to a statistically averaged “standard” person. Reduction in the error in dose estimation can be achieved by using as many individual indicators as possible, in particular, direct measurements of incorporated activity, characteristics of contamination of the area, migration of man during the most intense intake of iodine radionuclides in the summer of 1986 and individual diet.

The present work describes a methodology for calculating individual thyroid doses in part of the population in Bryansk and Kaluga regions, for whom measurements of incorporated thyroid ^{131}I activity were made in 1986. For Kaluga region we used verified data of individual thyroid radiometry for persons included in RNMDR and living at the time of the accident in Zhisdra, Ulyanovo and Khvastovichi areas. The model considers exposure of thyroid with incorporated ^{131}I taken in per os or by inhalation.

1. Dosimetric model for thyroid irradiation

The content of iodine radionuclides in the thyroid is determined by dynamics of radionuclide intake and removal. The balance of these processes is described by the following equation:

$$\frac{dh(t)}{dt} = b(t) - (\lambda + k_{out})h(t), \qquad (1)$$

$$h(t=0) = 0,$$

where $b(t)$, kBq·day^{-1} is the rate of radionuclide intake by man;

$h(t)$, kBq is the time dependent ^{131}I activity in thyroid;

λ is the decay constant for ^{131}I: λ = 0.0862 day^{-1};

k_{out}, day^{-1} is the rate constant of biological of ^{131}I from thyroid: k_{out} = 0.693/T_b; T_b is the half-life period, measured in days.

In this work we don't use the formulae from guidelines [12], as they are too awkward. Besides, our formal approach is different, but seems preferable to us. The main task in dose estimation is calculation of intake rate ***b(t)***. With the prescribed ***b(t)*** equation (1) takes the general form:

$$h(t) = e^{-\lambda_{eff} t}\int_0^t b(x) e^{\lambda_{eff} x} dx, \qquad (2)$$

where $\lambda_{eff} = \lambda + k_{out}$ is effective rate of radionuclides removal from thyroid.

Two main components determine the amount of activity entering the thyroid: per os with contaminated milk and by inhalation [9, 12, 13].

The studies of dynamics of iodine accumulation in milk of milking cows [14] have shown that the iodine concentration in milk is maximum on the 3-5th day after beginning of consuming contaminated forage. In model [15] modifying the classical model [16] the radionuclides concentration in milk is approximated with the following relation:

$$\begin{aligned} c_1(t) &= C_t \cdot g(t) \\ g(t) &= Q \cdot (e^{-rt} - e^{-st}), \end{aligned} \qquad (3)$$

where t, day is the time interval counted from the beginning of consumption of contaminated fodder;

$c_1(t)$, kBq·l^{-1} is the specific concentration of ^{131}I in milk;

C_t, kBq·day^{-1} is the initial rate of activity intake by cow;

Q, r, s are approximation parameters;

Q = 0.818 day·l^{-1}; r = 0.176 day^{-1};

s = 0.9 day^{-1}.

The approximation $c_1(t)$ in formula (3) implicitly accounts for the competing processes of chronic intake of iodine intake by cows with fodder and reduction in activity due to metabolic processes and radioactive decay. The approximation parameters are selected so that the model reproduces in the best possible way experimental results in terms of time of reaching maximum level of activity in milk and the value of integral activity secreted by a cow in milk [14, 15]. The parameters values used in our work were obtained for the beginning of the spring grazing season.

Model [15] predicts the milk contamination with one-time contamination of the environment, when at time moment t = 0 the initial contamination density σ^0, kBq/m^2 is formed. The initial rate of activity intake by a cow is proportional to the initial contamination density [14]:

$$C_t = \alpha \cdot \sigma^0, \qquad (4)$$

where α, (kBq/day)/(kBq/m^2) is the parameter accounting for activity transfer from grass and soil to cow milk.

Generalisation of the model [15] for long-term fall-out consists in the following. Let the contamination density be formed as a result of deposition n of portions of the radionuclide at moments t_1, t_2, ..., t_n, each of which contributed to the total contamination density, respectively σ_1, σ_2, ..., σ_n. Using (3) and (4) we get the dynamics of specific concentration of iodine radionuclides in milk at long-term depositions in the following form:

$$\begin{aligned} c(t) &= \sum_{i=1}^{n} c_1(t - t_i) = \\ &= \sum_{i=1}^{n} \alpha \cdot \sigma_i^0 (t - t_i). \end{aligned} \qquad (5)$$

The rate of ^{131}I activity intake by man is primarily influenced by milk consumption and duration of staying in the contaminated area in May-June 1986. The inhalation intake of activity is determined by the concentration of radioactive aerosol in the air near-surface layer $x(t)$, Bq/m^3 and lung ventilation rate w, m^3/day. The rate w is dependent on the age and can be estimated from the published data [13].

We have calculated the activity intake rate $b(t)$ with the formula:

$$\begin{aligned} b(t) = f \cdot \big[& k_{in}^m (c_1(t)L_1 + c_2(t)L_2) + \\ & + k_{in}^a x(t) w \big] \cdot \eta(t) \cdot s(t), \end{aligned} \qquad (6)$$

where f = 0.3 is the part of radionuclide activity passing from blood to thyroid;

k_{in}^{m} = 1 is the part of radionuclide activity passing from intestinal tract to blood;

k_{in}^{a} = 0.63 is the part of radionuclide activity passing from lung to blood [17];

$c_1(t)$, $c_2(t)$, kBq/l is the ^{131}I concentration in milk produced in the public and private sectors, respectively;

L_1, L_2, l/day is the consumption of milk produced by the state and private sectors, respectively;

$\eta(t)$ is a function accounting for migration of a person in the period of intense transfer of radioactive iodine in milk;

$s(t)$ is a function accounting for protection measures, for example administration of stable iodine etc.

It is known [9] that the contamination of milk from the private sector in the first period after the accident was, on the average, by a factor of p = 2-3 higher that from state farms. In our calculations we used the relation

$$L_1 = L_2 / p.$$

It should be pointed out that formula (5) is used for estimating concentration L_2 of ^{131}I radionuclide in milk of the private sector.

Function $\eta(t)$ is expressed by the following formula:

$$\eta(t) = \begin{cases} 1, & t \in \Delta t_a \\ 0, & t \notin \Delta t_a \end{cases}, \qquad (7)$$

where Δt_a is time of staying in the a-th populated point.

The age-dependent biokinetic parameters of intake and removal of radioactive iodine and weight of thyroid were taken from work [9] and are included in Table 1. The consumption of milk for children is taken to be 0.7 l/day [18].

For the adult population of Bryansk region a similar value of 0.7 l/day was obtained based on the poll results [9].

The absorbed thyroid dose rate $p(t)$ and accumulated by moment t dose $D(t)$ were calculated with the formula:

$$p(t) = k_d \frac{h(t) \cdot \langle E_\beta \rangle}{m}, \qquad D(t) = \int_0^t p(\tau) d\tau, \qquad (8)$$

where k_d is a coefficient accounting for dimensions of the quantities;

$\langle E_\beta \rangle$ is the mean energy of β-decay of ^{131}I -0.23 MeV/dec.;

m is the age-dependent thyroid weight.

In literature [9, 13, 19-21] one can find numerous estimates of biokinetic parameters permitting calculation of thyroid dose depending on age at a given absorbed activity.

Figure 1 shows the estimated absorbed thyroid doses from ^{131}I activity of 37 kBq transferred to man's blood as a function of age in comparison with the literature data.

As can be seen from Figure 1 the absorbed thyroid dose decreases approximately an order of magnitude with age. The main contribution to this dependence is made by the growth of thyroid weight (Table 1).

Therefore, for standard ^{131}I intake our estimates of absorbed thyroid dose are in good agreement with the literature data, since we used generally accepted values of the parameters. Hence, it may be concluded that future estimation of absorbed doses can be influenced only by measured activities of ^{131}I in thyroid and dynamics of its release to the environment.

Table 1

Biokinetic parameters of formation of absorbed thyroid dose used in the present work

Age, years	Thyroid weight, g [9]	Half-life, day [9]	Volume of lung ventilation, m^3/day [13]
0	1.6	-	-
0.54	1.7	16	8
0.75	1.8	18	8
1.5	2.5	20	8
2.3	3.8	25	8
5	4.8	30	11

6.5	6.5	35	11
8.5	8	40	14
10	9	50	14
11	9.7	55	14
12	10.5	60	17
13.5	12	65	17
15	13	70	17
>18	20	100	20

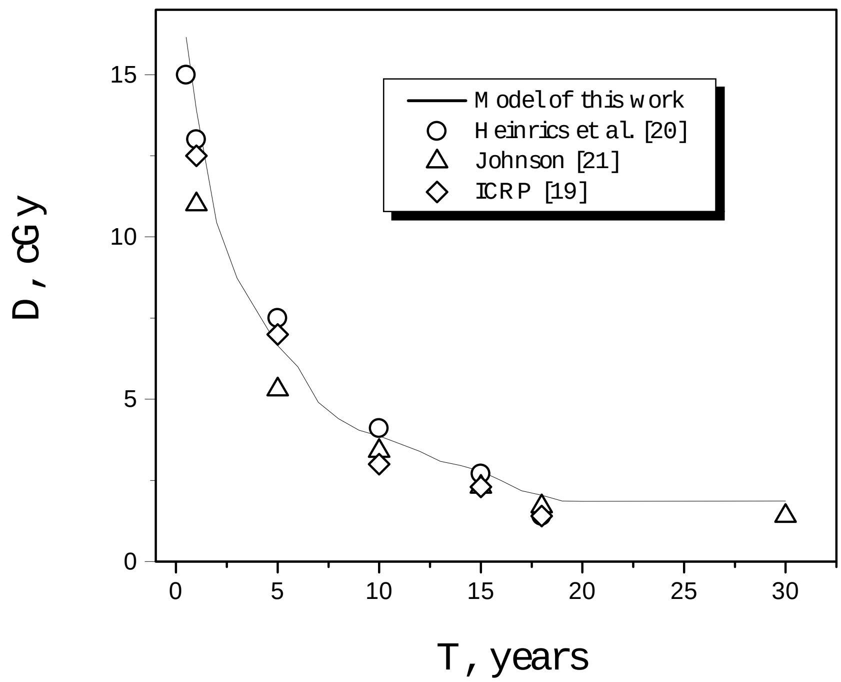


Fig. 1. Absorbed thyroid dose ***D*** as a function of age ***T***.
37 kBq of ^{131}I got into the blood.

The measured value of the incorporated activity at moment $t = t_i$ permits calculation of the individual intake rate $b_i(t)$ which is related to intake rate $b(t)$ (6) in the following fashion:

$$b_i(t) = b_0^i b^{\sim}(t)$$
$$b^{\sim}(t) = \frac{b(t)}{\int_0^{\infty} b(\tau)d\tau}. \qquad (9)$$

The constant b_0^i is found from condition $h(t_i)=A_i$, where A_i is measured value of individual activity at moment t_i. Using formula (2) we get:

$$b_0^i = \frac{A_i}{\int_0^{t_i} b^{\sim}(\tau)\exp[-\lambda_{eff}(t_i-\tau)]d\tau}. \qquad (10)$$

A similar method for estimating individual rate of iodine radionuclides intake by thyroid was used in work [9, 13]. In particular, in work [9] the intake rate was approximated by the following function:

$$b(t) = \begin{cases} b_0, t < t_0 \\ b_0 e^{(-k_0(t-t_0))}, t > t_0 \end{cases}, \qquad (11)$$

where t_0 = 15 days;
k = 0.693/T_1, T_1 = 5 days;

b_0 is activity intake rate for thyroid in the first period.

Thus, we have discussed the main details in estimation of the absorbed thyroid dose with long term fallout of ^{131}I.

Figures 2 and 3 show, as an example, results of reconstruction, using the method described in work [7] of the rate of ^{131}I release to the environment for four towns of Kaluga region (Zhizdra, Ulyanovo, Khvastovichi) and Bryansk region (Novozybkov). Figure 2 presents rates of ^{131}I deposition on the ground surface and Figure 3 - corresponding volumetric concentrations of ^{131}I in the air near-surface layer.

The presented results indicate a qualitative difference in the dynamics of formation of radioactive contamination in Bryansk and Kaluga regions which shows itself in the significant additional contamination on the territory of Kaluga region in the period 16-22 May 1986.

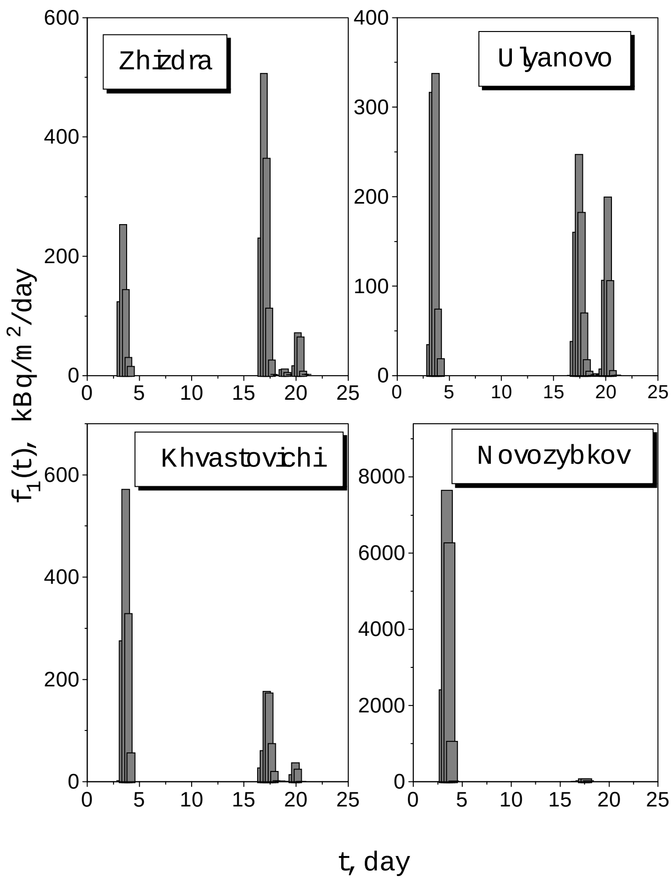


Fig. 2. Dynamics of ^{131}I influx to the soil surface [7] for some populated points in Kaluga and Bryansk regions which was used for estimating absorbed thyroid doses. The time interval ***t*** is counted from the time of the Chernobyl accident.

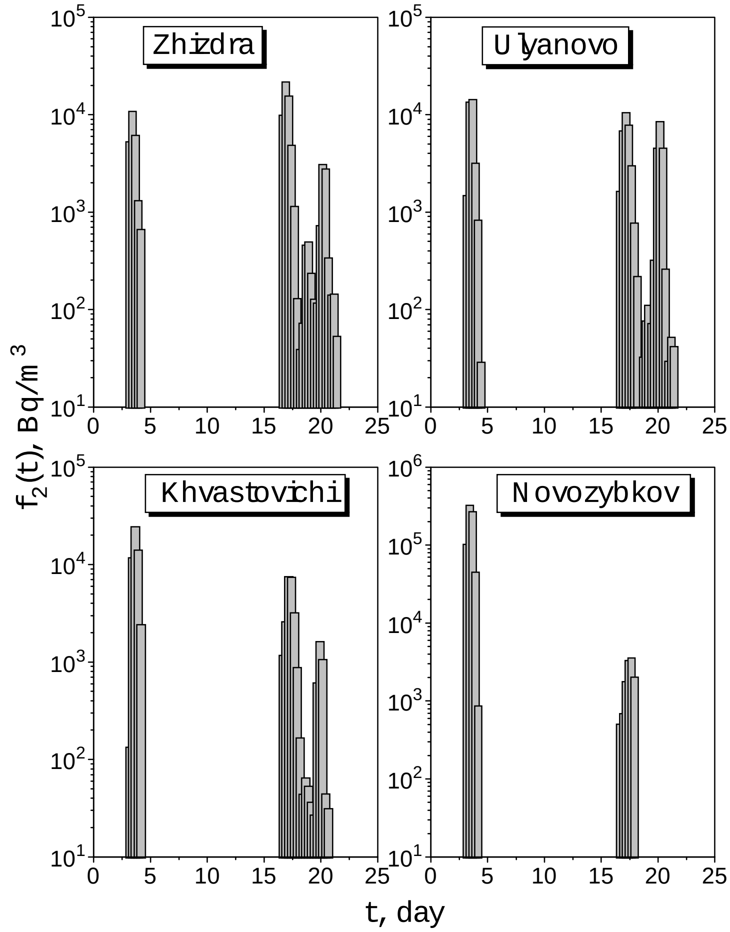


Fig. 3. Dynamics of the ^{131}I concentration in the air near-surface layer for some populated points of Kaluga and Bryansk regions reconstructed from data of [7] and used for estimating absorbed thyroid doses.

Figure 4 (the upper part) shows an example of a calculation of the individual rate of ^{131}I intake by thyroid of a 3-year old child. It was assumed that the child lived all the time in one of the specified populated points: Zhizdra, Ulyanovo, Khvastovichi of Kaluga region or Novozybkov of Bryansk region. The measurement of incorporated activity was presumably made on 25 May 1986, that is 29 days after the Chernobyl accident and it was 37 kBq. The intake rate calculated based on our model is also presented here [9].

The difference in our estimates of intake rate and those by model [9] for Bryansk region primarily applies to the period ***t*** **<** 15 days. The intake rate dependence for Kaluga region is qualitatively distinct from model [9] by having a second peak 20-21 days after the accident. It should be said that the presence of the second peak on the 20-21st day is not strictly proven by now. We are currently investigating in detail the dynamics of iodine depositions on the territory of the former USSR.

The same figure (lower part of Figure 4) shows the dynamics of ^{131}I incorporated activity in thyroid of a 3-year old child calculated with consideration of the estimated intake rate. All functions intersect in the point (***t*** = 29 day; ***A*** = 37 kBq) when the measurement was presumably made.

Data of Figure 4 demonstrate the importance of consideration of contamination dynamics when calculating absorbed thyroid dose even with direct measurements of incorporated ^{131}I activity. On the territory of Bryansk region the contamination dynamics is well described by the approximation of one-time deposition. For this reason, the calculations of this work and model [9] are in qualitative agreement for Bryansk region. The opposite is true for Kaluga region. The dose calculated by model [9] differs from that estimated by the model described in the present work approximately by a factor of 2 for Zhizdra of Kaluga region.

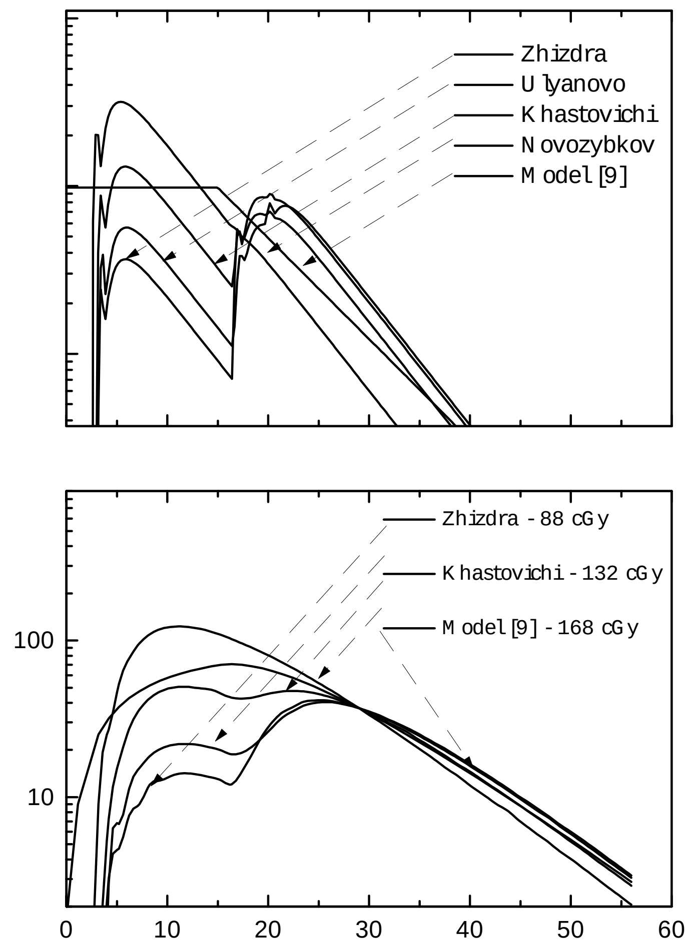


Fig. 4. Intake rate ***b(t)*** (upper part) and ^{131}I activity incorporated in the thyroid of a 3 year old child ***A(t)*** (lower part) calculated by our model and model [9]. The starting data: ^{131}I incorporated activity for 25 May 1986 - 37 kBq; the child lives in one of the indicated populated points all the time.

2. Verification of results of thyroid radiometry in the population of the contaminated areas in Bryansk region

The measurements of the activity of iodine radionuclides in thyroid for the population of Bryansk region used in this work were performed in May-June 1986 in the laboratory of clinic dosimetry of the Bryansk oncological dispensary with the methodological help of MNIRRI (Moscow) and NIIRG (St.-Petersburg). These data include 1619 measurements of incorporated activity in residents of the region and residents of other regions of CIS, mostly those evacuated from the zones of heavy radioactive contamination.

In the large-scale examinations of 1986 a radiometric unit "Gamma" was used. It was employed in the oncological dispensary for measuring incorporated activity of ^{131}I administered for diagnostic and medical purposes. This unit is based on a scintillation detector NaI (TI) with a cone collimator of 1 cm lead; the minor diameter is 4.5 cm and the major one - 13 cm, the length - 19.4 cm. During measurements the detector was placed at a large distance from a thyroid, which is the reason for using an approximation of a point source for irradiation of radionuclides incorporated in the thyroid.

The unit was calibrated in 1986 by a source of ^{131}I with a known activity which was placed in a flask for injections. During the calibration of the "Gamma" unit radiometer the source was in a lead container. For measurements the container lid was opened and the container was connected with a collimator with a detector and then the counting rate N_s above the flask was measured. For assessment of incorporated activity of ^{131}I the following relation was used

$$A_i = \frac{A_s}{N_s}(N_1 - \varepsilon \cdot N_2), \qquad (12)$$

where N_1, pulse/s is the counting rate of the unit when the collimator edge is near the chin;

N_2, pulse/s is the counting rate of the unit when the collimator edge is on the thigh of the patient;

ε is a coefficient accounting for "glow" of the detector by γ-radiation of cesium radionuclides incorporated in the body of the patient (in this work the value ε is taken to be = 0.9 [22]);

A_s is activity of the ^{131}I in the calibration source;

N_s, pulse/s is the counting rate of the unit from a calibration source;

A_i is the estimated activity in thyroid.

The time of measurement of incorporated activity and activity of the calibration source was not taken down during the studies of 1986, but as reported in [23] it was constant and was equal to 120 s.

During the time period when the intake of ^{131}I by thyroid was most significant, and this lasted for about two months after the accident, several calibration sources of ^{131}I were used in "Gamma". We have not found any records in the logs, in which measurements were registered, what sources of ^{131}I and what time interval were used. To answer this question we considered the time dependence of their activity (the logs contain for each patient an activity of the control source and a number of pulses recorded by the unit). The activities of control sources (in logarithmic scale) depending on time interval since the accident are shown in Figure 5 (the upper part) with estimated decrease in activity due to radioactive decay of ^{131}I. When three control (calibration) sources are used in measurements, the plot should show three series of points fitting the straight lines in keeping with ^{131}I decay.

As is seen from Figure 5 it can be assumed that 4 calibration sources were used in the "Gamma" unit. Nevertheless, for the first series (to 30 days after the accident) the activities of the control sources were close to the theoretical curve except the interval 17-19 May 1986 (21-23 days). Considering that the later measurements of the control sources in this series are close to the theoretical curve (i.e. this curve can be assumed to originate from one of the control sources) we introduce adjustments for the mentioned time interval. Thus, for the period 17-19 May 1986 we have reduced the activities of the control sources according to the records in the logs so that they correspond to decay of the same control source of ^{131}I. This procedure, of course, does not guarantee obtaining reliable data from measurements of incorporated activity in the considered period, but we have not found any better way to explain and eliminate the detected contradictions.

An important technical characteristic of the unit is stability of sensitivity during measurements. In 1994 we experimentally determined the sensitivity of the unit using calibration sources of ^{131}I. These works were conducted together with the laboratory of clinical dosimetry of the Bryansk oncological dispensary. For calibration of the unit, whose operation during counting was controlled by a spectrometer, we used two ^{131}I sources with the activity of 6.9 μCi (0.255 MBq) (01.11.1994) and 10.68 μCi (0.395 MBq).

The radioactive solution of ^{131}I was placed in two sealed polyethylene cylindrical capsules of 1.25 diameter and 4.5 cm length. Each vial contained 5 ml of the solution with radionuclides of ^{131}I. The resulting sources were calibrated in 4π-geometry in the laboratory of radioisotopic methods of MRRC of RAMS.

During the calibration of the " Gamma" unit using the indicated sources of ^{131}I in 1994 the energy resolution of the detector used in May-June 1986 measurements was determined The resolution on the main line of ^{131}I was 18%. The measurements were performed with the following geometry:

1) two sources of ^{131}I were arranged along the horizontal surface in the form of the letter V at an aperture angle of 45°;

2) a detector with the collimator was placed vertically above the sources at different distances from the horizontal surface.

During the measurements in May-June 1986 the edge of the detector collimator was aligned horizontally near the chin of the examined person. For estimating the effect of screening of iodine radionuclides irradiation in thyroid by the adjacent tissues we conducted measurements of irradiation from a source of V-shape with allowance for screening of the source by organic glass of different thickness. Depending on the age of the patient the distance between the front edge of the collimator and the skin surface in the area of thyroid was varied from 3 to 7 cm. The geometry of measurements and parameters were selected so that the 1986 measurement conditions could be simulated.

The current monitoring of measurements with use of a multichannel spectrometer with a personal computer has made it possible to establish the lower and upper thresholds for discriminating a detector signal in such a way that the photopeak of absorption of ^{131}I radiation could be recorded in full. The number of pulses recorded by the unit by not more than 0.5% differed from the photopeak area estimated from a computer spectrum. The results of measurements are presented in Table 2.

As can be seen from data of Table 2, with the change in distance between the collimator edge and source plane of 4 to 6 cm the recording rate decreases by 17% in measurements without screening. A screening of 5 mm of organic glass leads to reduction in the fluence of unscattered radiation by another 5%. So, only due to the uncertainty in the geometry of measurements in 1986 the error in determination of incorporated activity of ^{131}I could be 20-25%.

In Table 2 results from 8 to 10 were obtained in measurements of sources at a distance of 5 cm with the screening of organic glass, and result 11 - measurements in a half-opened container. The analysis has shown that measurements compare well within the error. Hence, results of the calibration of the " Gamma" unit in 1986 using the methodology accepted at that time based on measurement of sources in a half-opened lead container can be considered as justified. A possible methodological error due to the uncertainty in measurement geometry could reach 25%. A greater error in measurements could have been brought in by measurement of activity of the calibration source in 1986 and measurements of discrimination thresholds.

Figure 5 (lower part) presents the sensitivity of " Gamma" unit estimated based on the log records of 1986 as a function of time for the performed large-scale measurements. In this figure the solid line shows the sensitivity measured by us in 1994. By data of 1994 (Table 2) the sensitivity of " Gamma" was about 0.15 pulse/s/kBq. But according to the records of measurements in the logs it changed from 0.00067 to 0.46 pulse/s/kBq. A sharp change in the unit sensitivity 30-45 days after the accident was the result of construction modifications of the operating unit [22].

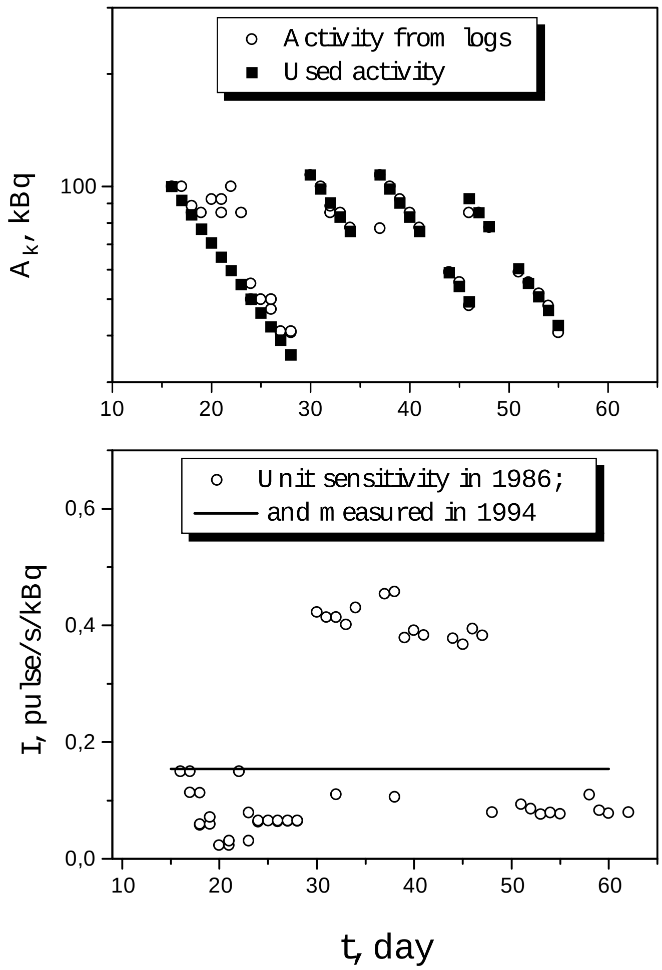


Fig. 5. Measurement of characteristics of the radiometric unit "Gamma" in 1986 estimated from records in logs and from our calibration data of 1994.
$\boldsymbol{A_k}$ is the activity of ^{131}I calibration source; ***I*** is the sensitivity of "Gamma" unit; ***t*** is the time after the accident.

Table 2

Results of calibration measurements of ^{131}I sources with the radiometric unit "Gamma" of the Bryansk oncological dispensary in 1994

d is the distance between the collimator edge and the surface on which the sources were placed, cm;
*Δ**l*** is the thickness of organic glass screening, mm;
N is the number of pulses registered in the area of ^{131}I photopeak over the time interval *Δ**T*** = 60 s (minus background);
n is the counting rate, pulse/s;
The measurement background was, on the average, 25 pulses per 60 s.

^{1}	***d***, cm	*Δ**l***, mm	***N***, pulse	***n***, pulse/s
1	4	0	6521	108.7
2	6	0	5533	92.2
3	10	0	4225	70.4
4	14	0	3370	56.2
5	4	0	6699	111.7
6	4	2.15	6430	107.2
7	5	0	6085	101.4

8	5	2.15	5898	98.3
9	5	4.9	5820	97.0
10	5	8.4	5611	93.5
11*	6.5	0	5742	95.7
12*	9	0	4740	79.0
13*	12	0	3606	60.1

* - The measurements were conducted in the same way as in 1986. The detector was placed above the lead container with the ^{131}I calibration source.

A significant change in the unit sensitivity during the period of large-scale examinations could have led to wrong estimates of activity in thyroid if measurements of the calibration source and of the patient had been conducted at different time. But since the measurement procedure was based on comparison of activity in thyroid and activity of calibration source estimated at the same time, i.e. at the same sensitivity of the unit [23] it may be considered that the measurement results are acceptable for further estimation of absorbed thyroid doses.

3. Analysis of results of thyroid radiometry in the population of the contaminated areas in Kaluga region

Measurements of ^{131}I activity incorporated in thyroid in residents of populated points in Kaluga region were performed in May-June 1986 by teams of MRRC of RAMS. In the large-scale examination thyroid doses were estimated by one-time measurement of γ-radiation dose rate near a throat with a radiometer of FSR-68-01 (Field Scintillation Radiometer) type [26]. According to this method ^{131}I activity in thyroid at time moment t_0 can be estimated by the formula:

$$A = k \cdot G \cdot [P_1(t_0) - P_3(t_0)], \quad (13)$$

where k is the adjustment coefficient of a specific device varying from 1 to 1.6;

G is a calibration constant relating the unit readings with ^{131}I activity in thyroid and equal to 1/180 μCi (μR/hour);

$P_1(t_0)$ is the dose rate near thyroid;

$P_3(t_0)$ is the dose rate in the room where the measurements are made without a patient.

It is relevant to say at this point that the methodological guidelines [12] recommend that as $P_3(t_0)$ one should use a result of dose rate measurement with the detector placed right up to the humeral part of the arm of a patient. It is also suggested that the following values of the calibration coefficient G be taken:

1/710 - for children of less than 3 years old;

1/540 - for children of 3 to 10 years;

1/360 - for all other patients.

In work [24] the values recommended for the coefficient G are:

1/290 - for children of 1 to 8 years;

1/250 - for children of 8 to 16 years;

1/220 - for all other patients.

The methodological guidelines [25] recommend the value of 1/165 for the coefficient G.

As can be seen, different works recommend the values of the calibration coefficient which are significantly different from each other, particularly in work [12], and this may significantly influence the estimate of ^{131}I incorporated activity.

Formula (13) implicitly assumes that P_1 is contributed only by irradiation of ^{131}I accumulated in thyroid and that the patient body does not screen significantly the detector of radiometer-dosimeter FSR-68-01. In reality the so-called ‘physiological” distribution of iodine leads to its occurrence in blood, salivary glands, IT, bladder and other organs. One should also expect radionuclides of cesium in the body of a patient living on the contaminated area. These factors can be taken into account if another measurement P_2 is made, for example, near a thigh or liver and the value of screening of the background radiation near the measured parts of body is known.

Let us designate time dependencies $q_s(t)$ as ^{131}I activity in thyroid (s=1), ^{131}I activity outside thyroid (s=2) and ^{137}Cs activity in the whole body (s=3) for a given person. Let $k_s^{x,y,t}$ be the conversion coefficient from activity to dose rate measured with a detector on the body surface in the point with coordinates (***x,y***) at time moment ***t***; $\delta^{x,y,t}$ - the coefficient of screening of the detector by the body in point (***x,y***) at moment ***t***.

The general equations determining dose rate at time moment t_i in points 1 (near larynx - P_1) and 2 (near liver - P_2) can be written as:

$$P_r(t_i) \equiv P_{ri} = \sum_{s=1}^{3} k_s^{ri} \cdot q_s^i + \delta^{ri} \cdot P_{3i},$$

$$r = 1,2. \qquad (14)$$

For solution of this system with respect to q_1^1 some assumptions and additional measurements should be made.

Table 3 presents results of our model studies of screening of the detector FSR-68-01 (irradiation variants 1-8) and detector of “ Photon” dosimeter (irradiation variant 9). A polyethylene tank (phantom) of 34×30×10 cm^3 and 10 l volume filled with water was placed at a height of 40 cm vertically or horizontally, thus simulating different parts of the body for a sitting person (child).

The γ-radiation in the room where the radiometric study was performed in 1986 was simulated with γ-irradiation from natural sources in brick houses with concrete ceilings and γ-irradiation of simulated ring sources of 2 m radius: ^{131}I; ^{131}I in a protected lead container of 20 mm thick; ^{137}Cs. The ring source was simulated by rotating the phantom by 45° around the detector at the same position of the point source and detector. The screening coefficient δ was calculated as a ratio of mean values of dose rates with and without a phantom and for the ring source by integration of δ for all positions of the phantom.

As follows from data of Table 3, when using the radiometer-dosimeter FSR-68-01 the effect of detector screening by the phantom was not observed, which seems to be explained by a better efficiency of the scintillation detector FSR-68-01 to register the scattered and reflected radiation which is softer than the incident one. Measurements with a gas-discharge detector of dosimeter “ Photon” , in which working with hardness is compensated with the accuracy of 30% in the energy interval 0.1-4 MeV, support this assumption (variant 9 of Table 3).

Table 4 shows results of our estimation of the screening coefficients of γ-irradiation of natural sources when the detector FSR-68-01 is placed near larynx (δ^{1I}) and liver (δ^{2I}) of a sitting person. These coefficients do not practically differ for a given person, they are close to unity, but are decreasing with height and weight. In further calculations it was assumed that $\delta^{1i} = \delta^{2I} = \delta^I = \delta$ and equals 1.0 for children to 14 years; 0.95 for adolescents from 14 to 18 and 0.90 for persons older 18 years.

For estimation of ^{131}I thyroid incorporated activity the system (14) should be solved with respect to q_1^1. Let us introduce additional quantities:

$$\varepsilon^{Cs} = \frac{P_{12} - \delta^2 \cdot P_{32}}{P_{22} - \delta^2 \cdot P_{32}};$$

$$\varepsilon^{I} = \frac{P_{13} - \delta^3 \cdot P_{33}}{P_{23} - \delta^3 \cdot P_{33}},$$

which can be estimated from measurements of dose rate near larynx and liver, given only Cs or I radionuclides occur in the body of a patient, respectively. Then, considering (14) and equality of screening coefficients $\delta_1 = \delta_2 = \delta$ ^{131}I activity in thyroid at the moment of measurement of dose rate near larynx and liver will be determined by the formula:

$$A \equiv q_1^1 = \frac{k \cdot G}{\gamma}\Big[P_{11} - \varepsilon^I \cdot P_{21} - \frac{q_3^1}{q_3^2}(\varepsilon^{Cs} - \varepsilon^I) \cdot (P_{22} - \delta^2 \cdot P_{32}) - \delta^1 \cdot (1 - \varepsilon^I) \cdot P_{31}\Big]. \qquad (15)$$

Where the adjustment coefficient γ is determined by

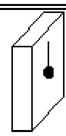
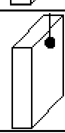
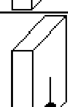
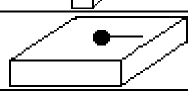
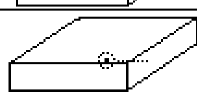
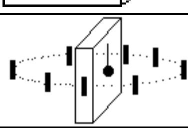
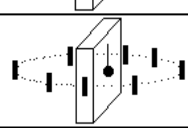
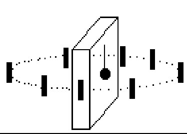
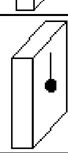
$$\gamma = 1 - \frac{k_1^{21}}{k_1^{11}} \cdot \frac{k_2^{11}}{k_2^{21}}$$

and primarily accounts for the contribution of γ-irradiation of thyroid in dose rate measurements near liver. Our measurements simulating conditions of individual radiometry in 1986 show that this coefficient can be taken to be 1 even for newly-born with accuracy not worse than 10%. For older persons the approximation error γ=1 is much less.

The value of ε^{Cs} (we will refer to it as a coefficient of illuminating of the detector FSR-68-01 by γ-irradiation of ^{137}Cs used in thyroid radiometry) was estimated from results of our measurements of dose rate near larynx and liver with the detector FSR-68-01 among 73 residents of Ulyanovo district of Kaluga region in July 1986, when radioactive iodine had practically decayed. For further analysis 21 persons were selected for whom results of dose rate measurements were considerably (not less than 1.5 times) higher the dose rate in the room. Figure 6 presents values of coefficient ε^{Cs} as a function of age. The analysis has not revealed any significant dependence of ε^{Cs} on age. The mean value of ε^{Cs} was 0.875±0.026.

Table 3

Screening coefficient δ of detector of radiometer-dosimeter FSR-68-01 (variants 1-8) and dosimeter "Photon" (variant 9) using γ-irradiation of natural and man-made (^{131}I, ^{137}Cs) sources of phantom irradiation

Irradiation geometry variant	Phantom and detector position	Sources of γ-irradiation	Dose rate, μR/hour	δ
1		Natural	11.39 ± 0.06	1.041 ± 0.010
2		Natural	11.05 ± 0.10	1.039 ± 0.019
3		Natural	11.49 ± 0.10	1.063 ± 0.020
4		Natural	11.25 ± 0.10	1.001 ± 0.010
5		Natural	11.46 ± 0.10	1.092 ± 0.01
6		Natural + ring source of ^{137}Cs	23 ± 1[1]	1.00 ± 0.10
7		Natural + ring source of ^{131}I	377 ± 15[1]	1.00 ± 0.08
8		Natural + ring source of ^{131}I in screened container	132 ± 6[1]	1.05 ± 0.09
9		Natural	12.16 ± 0.14[2]	0.962 ± 0.025

1 - the natural background in the room was 12.65 ± 0.11 μR/hour;

2 - in measurements with the dosimeter FSR-68-01 the dose rate was 8.09 ± 0.04 μR/hour.

Table 4

Coefficients of screening of γ-radiation of natural sources with the detector of FSR-68-01 dosimeter placed near larynx δ_1 and liver δ_2 depending on antropometric indicators of a patient

¹	Weight, kg	Height, cm	Larynx		Liver	
			Dose rate*, μR/hour	δ_1	Dose rate*, μR/hour	δ_2
1	115	172	8.41 ± 0.18	0.95 ± 0.03	8.54 ± 0.17	0.90 ± 0.03
2	80	180	11.22 ± 0.11	0.91 ± 0.02	11.48 ± 0.11	0.89 ± 0.02
3	66	172	8.29 ± 0.17	0.91 ± 0.03	8.20 ± 0.19	0.93 ± 0.04
4	56	165	11.22 ± 0.11	0.92 ± 0.02	11.48 ± 0.11	0.95 ± 0.02
5	55	165	11.22 ± 0.93	0.93 ± 0.02	11.48 ± 0.11	0.95 ± 0.02
6	15	95	8.07 ± 0.13	1.00 ± 0.03	8.07 ± 0.13	1.01 ±0.04

* - a mean dose rate for a series of measurements in the point of detector without a patient.

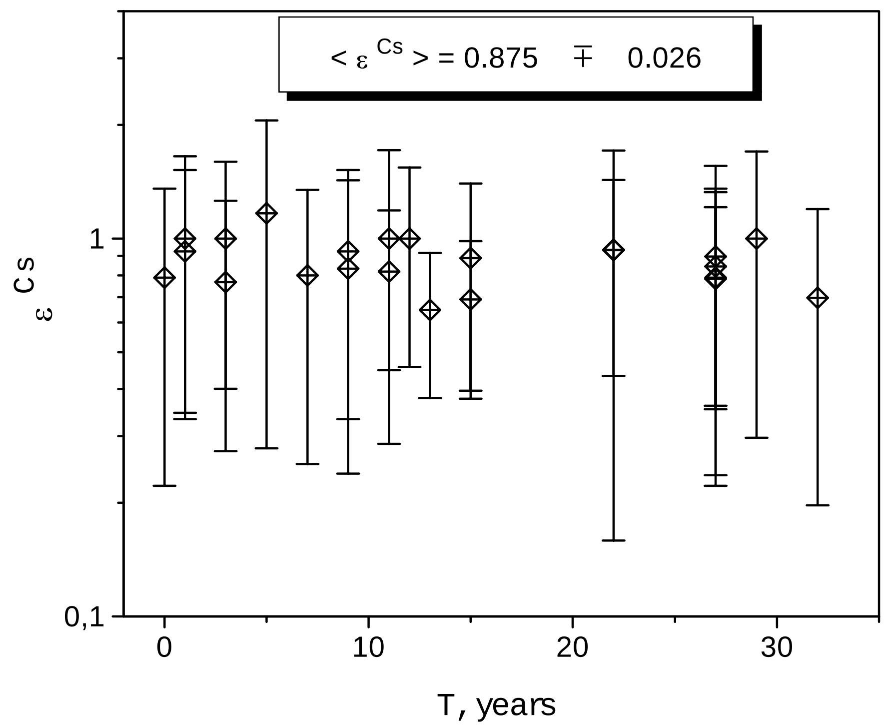


Fig. 6. Coefficient ε^{cs} estimated from measurements of dose rate near larynx and liver performed in July 1986 depending on age (***Ò***) of a patient.

The mean value ε^{I} was calculated by the results of dose rate measurements near larynx and liver in 3 patients with removed thyroid, approximately a week after oral administration of sodium iodide with ^{131}I in the department of treatment with open radionuclides of MRRC of RAMS and it appeared to be 1.13±0.09. During computer scintigraphy of these patients ^{131}I was found to be fixed in salivary glands and IT. These examinations were made with patients with an empty bladder in which significant amount of iodine to be excreted from the body can accumulate. Unfortunately, this requirement was not observed during the large-scale radiometric measurements in Kaluga region in 1986. The presence of ^{131}I in the bladder increases its contribution to dose rate near liver in estimation of ε^I which leads to reduction in ε^I. With this in mind we used the approximation $\varepsilon^{Cs} = \varepsilon^I = \varepsilon = 0.875$. Considering all the assumptions made the formula (15) can be written as:

$$A = k \cdot G \cdot [P_{11} - \varepsilon \cdot P_{21} - \delta \cdot (1 - \varepsilon) \cdot P_{31}]. \qquad (16)$$

Comparing formulae (13) (the activity calculated by it will be designated as A_1) and (16) (the activity calculated by it will be designated as A_2) it can be shown that accounting for illumination and screening of detector FSR-68-01 leads to a change in individual estimated activity by value Δ:

$$A_1 - A_2 = \Delta = k \cdot G \cdot [\varepsilon \cdot (P_{21} - \delta \cdot P_{31}) - (1 - \delta) \cdot P_{31}]. \qquad (17)$$

As is seen from formula (17), the displacement value depends on incorporated activity of cesium radionuclides (through dose rate in the area of the liver - P_{21}), external dose rate in the room where the measurements of incorporated ^{131}I activity (P_{31}) were made and patient age (through the screening coefficient δ). Parameter Δ can have different values because of two competing factors: illumination and detector screening. From fully verified data of individual radiometry in 1986 (measurements near larynx and liver) for 747 residents of Kaluga region we selected those pairs for which the unit readings near larynx and liver are not less than 1.5 times higher the dose rate in the room where the individual radiometry of thyroid was performed. By this group of 82 persons, we estimated mean value of adjustment Δ: 3.41±0.41 kBq (0.092±0.012 μCi). Results of comparison of estimates of incorporated ^{131}I activity by formulae (13) and (16) are presented in Figure 7.

As can be seen from the figure individual Δ are mostly close to the above mentioned mean value. This gives ground for using a mean value of Δ for a group of patients in Kaluga region with no data of dose rate measurements near liver.

Thus, the performed analysis of part of data of individual radiometry of thyroid in some areas of Kaluga regions in May-June 1986 has shown that they can be applied to estimate absorbed thyroid doses after introducing corresponding adjustments.

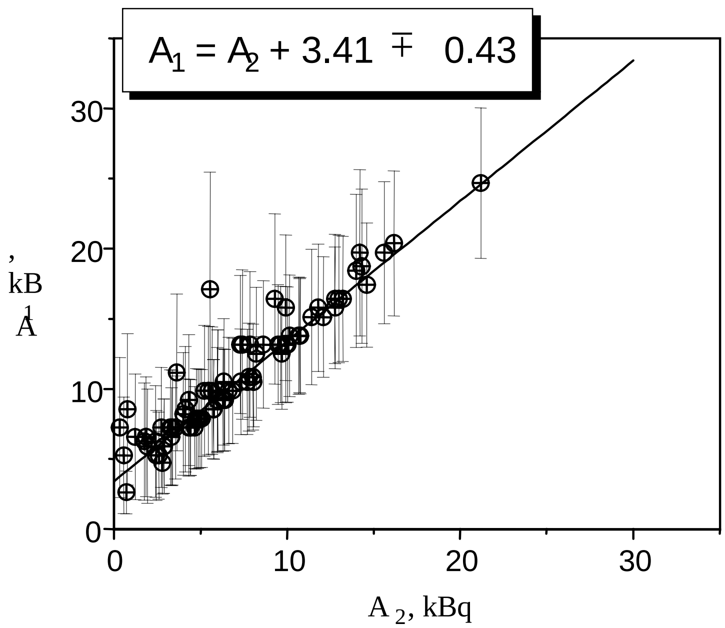


Fig. 7. The significance of taking into account cesium and iodine radionuclides distributed in the whole body (“ illumination”) and background screening in measurements of ^{131}I incorporated activity in thyroid. $\boldsymbol{A_1}$ is estimated ^{131}I activity without considering of “ illumination” and screening of FSR-68-01 detector; $\boldsymbol{A_2}$ is estimated ^{131}I activity with consideration of “ illumination” and detector screening. The solid line and formula is a regression ratio of $\boldsymbol{A_1}$ and $\boldsymbol{A_2}$.

4. Absorbed thyroid doses from incorporated ^{131}I

Results of individual measurements of incorporated activity in residents of two populated points in Bryansk and Kaluga regions are shown in Figures 8 and 9 for different age groups. The figures indicate the mean incorporated activity of ^{131}I and standard errors in mean values (given sufficient number of measurements) depending on time. The solid line shows a calculated theoretical time dependence of incorporated ^{131}I activity in thyroid.

The calculations were made for the mean age for the group and mean transfer rate estimated from individual measurements and characterised by a radioecological parameter α in the model (see (4)).

The comparison of instrumental measurements and calculations with our model indicates that the large-scale examination of the population in Bryansk region was started several days after the predicted time of reaching the maximum concentration of ^{131}I incorporated activity in thyroid. The measurements continued till complete radioactive decay of ^{131}I. The analysis of data in Figures 8 and 9 shows that the large-scale examination in Kaluga region was started soon after reaching the second predicted maximum. The qualitative difference from Bryansk region was that the examination in Kaluga region was carried out for a short time, but it covered practically all children population of the contaminated territories [10].

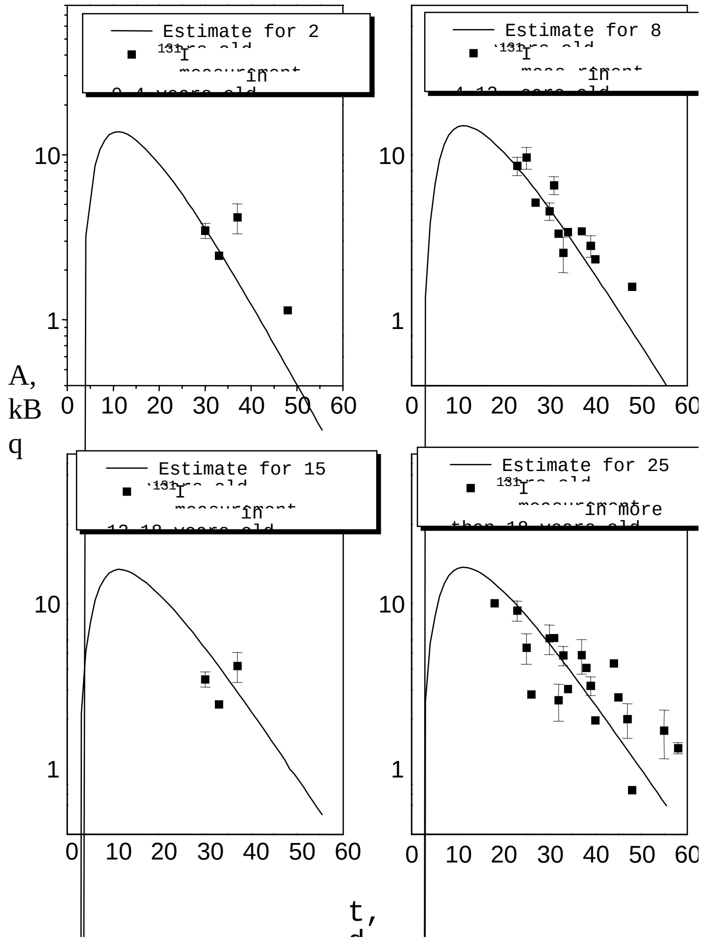


Fig. 8. Mean measured activities of ^{131}I in thyroid ***A*** for different age groups of residents of Novozybkov, Bryansk region as a function of time; ***t*** is time after the accident. The solid line is calculation by our model for mean intake rate of ^{131}I activity in the thyroid determined by the coefficient α = 0.16, see (4).

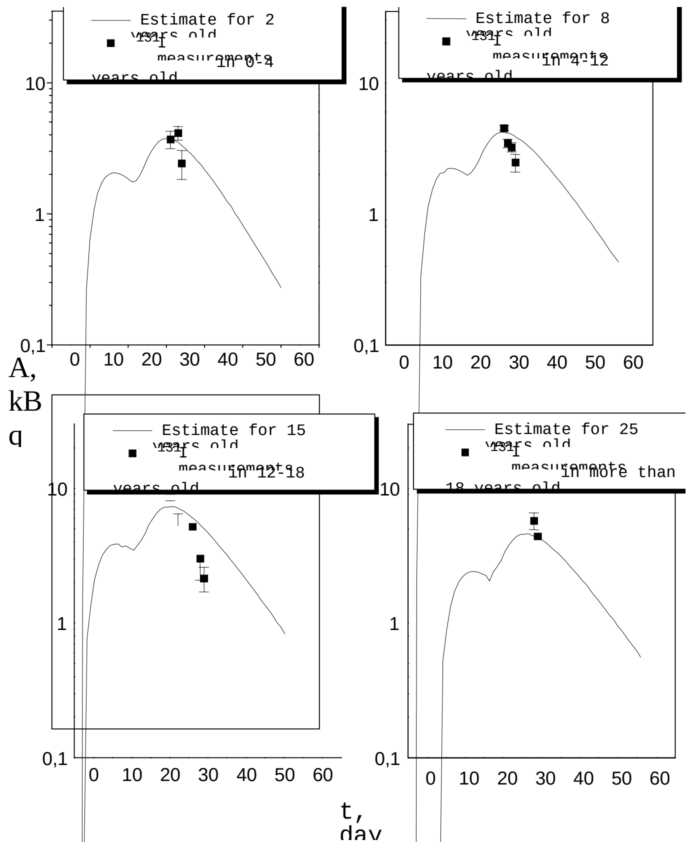


Fig. 9. Mean measured activities of ^{131}I in thyroid ***A*** for different age groups of residents of the Ulyanovo, Kaluga region as a function of time ***t*** after the accident, α = 0.55.

Figures 10-13 present distributions of residents of Bryansk and Kaluga regions (by the results of individual radiometry available to the author, ***it is these groups that are implied later on, when reference is made to residents of Bryansk and Kaluga regions***) with respect to absorbed thyroid doses for different age groups.

The analysis of the results in Figures 10-13 leads us to make the following conclusions. Mean absorbed thyroid doses decrease by a factor of 5 to 10 when passing from a younger age group to adults in agreement with the known dependence (Figure 1). The indicated trend is observed for residents of both Bryansk and Kaluga regions. The distributions show that a significant part of doses exceeding both probable and mean values by a factor of 5 to 10. This is because of individual features in diet, time of staying in the contaminated areas and other factors determining individual absorbed dose.

The mean absorbed thyroid doses in Bryansk region, according to our calculations, are higher those in Kaluga region by a factor of 5 to 15 for different age groups (see text in italics below Figure 8). The ratio of absorbed thyroid doses for the population of the two regions reflects features of radioecological situation in May-June 1986. The essential contamination of the territory of Bryansk region occurred on 28-30 April 1986 and was characterised by the high density of surface contamination with iodine radionuclides as compared with the territory of Kaluga region [4, 7].

The mentioned radioecological features were confirmed quantitatively by the total of individual doses derived based on reconstruction of ^{131}I contamination dynamics and measurements of thyroid incorporated activity of ^{131}I.

It should be noted that the mean doses for Bryansk region calculated in this work for separate populated points cannot be used for the whole region and they may differ from those used in [9] for estimating collective dose and predicting incidence of radiation induced thyroid neoplasms.

Work [9] contains doses calculated in two ways: without consideration of protection measures and considering large-scale protection measures during 8-15 day after the accident. With identical starting data on incorporated activity our estimates of absorbed doses are somewhat higher the variant presented in [9] without consideration of protection measures, but lower calculations in [9] assuming that protection measures were implemented.

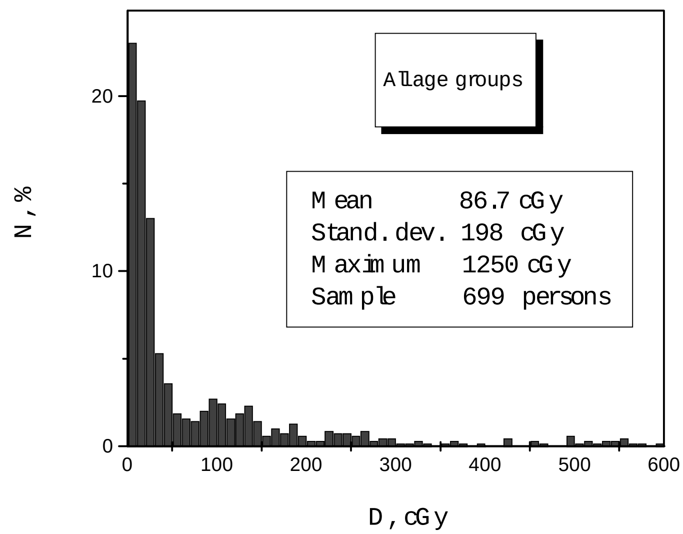


Fig. 10. Distribution of residents of contaminated populated points of the Bryansk region by absorbed thyroid dose ***D*** for all age groups; ***N*** is the percentage of examined patients.

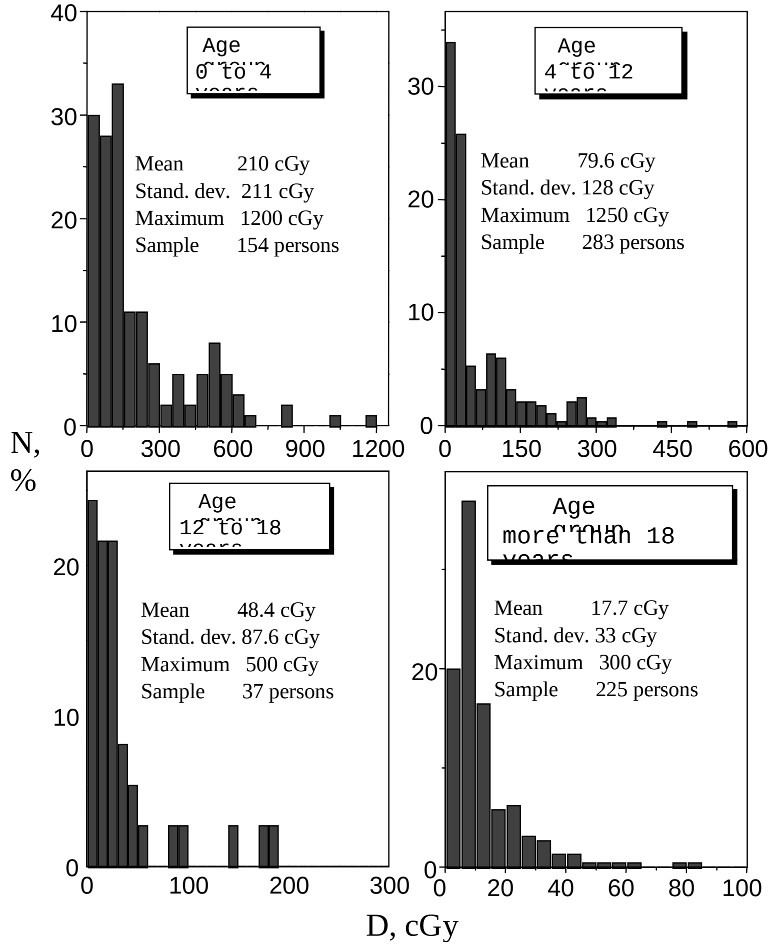


Fig. 11. Distribution of residents of contaminated populated points of the Bryansk region by absorbed thyroid dose ***D*** for different age groups; ***N*** is the percentage of examined patients.

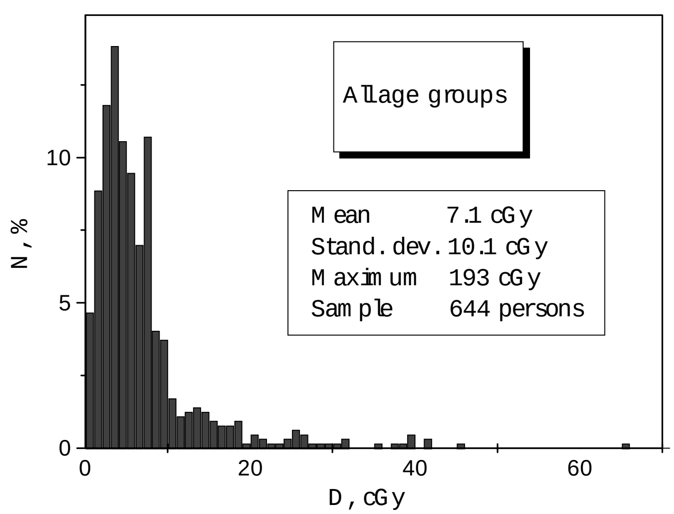


Fig. 12. Distribution of residents of contaminated populated points of the Kaluga region by absorbed thyroid dose ***D*** for all age groups; ***N*** is the percentage of examined patients.

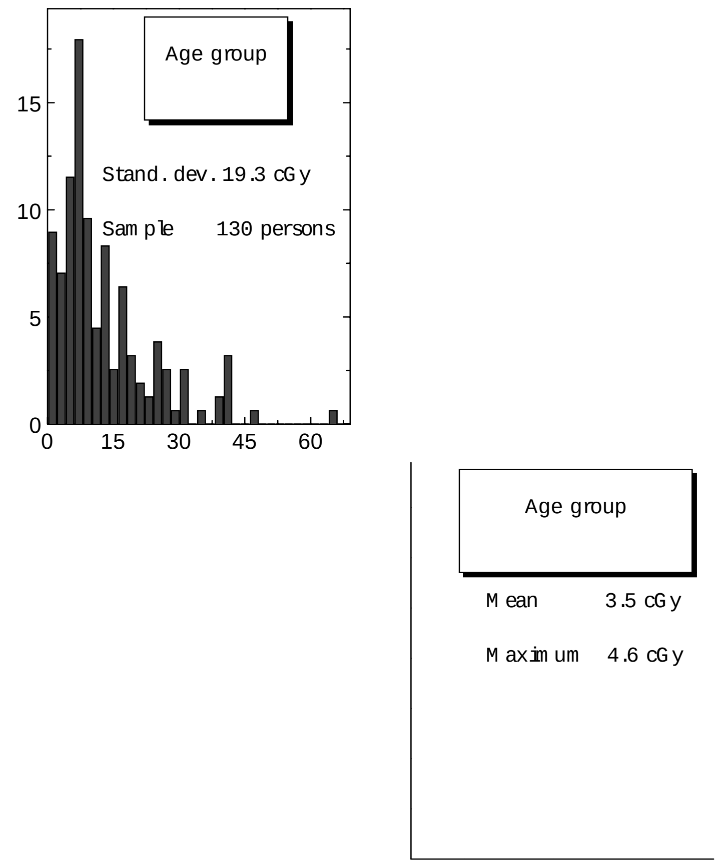


Fig. 13. Distribution of residents of contaminated populated points of the Kaluga region by absorbed thyroid dose ***D*** for different age groups; ***N*** is the percentage of examined patients.

In our calculation we did not use data of work [9] on implemented large-scale protection measures restricting the oral intake of radioactive iodine with contaminated milk. This aspect of dose estimation is planned to be analysed in detail in next publication, which will include data of individual polling of the population in the contaminated areas of Bryansk and Kaluga regions.

Data of individual thyroid radiometry needed for correct estimation of absorbed thyroid dose for residents of contaminated areas are much more scarce than the number population itself. Therefore, estimation of population dose requires using some other methods. The most wide-spread method is estimation of the absorbed thyroid dose by mean density of ^{137}Cs depositions in a populated point [9, 11] using the statistical hypothesis:

$$\boldsymbol{D} = \boldsymbol{a} + \boldsymbol{b} \cdot \boldsymbol{\sigma}, \qquad (18)$$

where ***D*** is the mean absorbed thyroid dose for a group of persons;

a, b are parameters;

σ is the mean density of soil contamination with ^{137}Cs.

In work [9] parameter ***a*** in equation (18) is taken to be 0; in work [11] it is not 0 and dependent (as is parameter ***b***) on geographical location of a given populated point (belonging to a certain administrative area). A strict statistical analysis of hypothesis (18) should take into account the following consideration which is of principal importance.

Individual absorbed thyroid dose ***D*** is a random value with an unknown, in a general case, distribution law. The presented distributions of absorbed doses (Figures 10-13) show that the ***D*** distribution law is rather complex. It can be assumed that it is close to alog normal distribution (for all distributions in Figures 10-13 the mean square deviation of absorbed dose of the order of magnitude of the mean value).

Hence, for a strict analysis of hypothesis (18), in fact, one should introduce an additional quantity $\Re$ - a lognormally distributed random value with a zero mathematical expectancy and an unknown variance $s_{\Re}^2$ (which should be estimated as are parameters ***a*** and ***b***). The unknown variance $s_{\Re}^2$, in a general case is dependent on σ and its distribution law (which is lognormal too).

After finding the parameters of equation (18) by the method of likelihood maximum, using a given sample one should verify the proposed hypothesis about a random value $\Re$ (zero mathematical expectancy and belonging to the class of lognormal distributions). Only after such a procedure, providing statistical significance of parameter estimates, can the frequently used formula (18) be considered to be well justified. In works [9, 11] such estimates have not been derived, but the standard formulae of the least square method are used (for random values with the normal distribution law).

Therefore, hypothesis (18), in the strict sense of the word, can not be considered justified. In the following article we will discuss this issue based on a better knowledge of the dynamics of depositions of radionuclides considering data of collectors [2]. We are also going to address the rest data of individual radiometry after their verification. In the present work only starting data for such analysis will be presented.

Figure 14 compares the mean absorbed thyroid doses for different age groups of residents in Bryansk region with mean density of ^{137}Cs contamination of populated points. The figure also shows estimated correlation coefficient ***r*** between individual values of absorbed thyroid doses and mean density of ^{137}Cs contamination of populated points. As can be seen from the figures the low value of the correlation coefficient does not allow us to propose, at his stage, a hypothesis on linear relation of mean absorbed thyroid dose and mean density of ^{137}Cs contamination of the populated point.

The ratio of absorbed thyroid doses and mean ^{137}Cs contamination density can be estimated wrong if residents of cities and town are included in the analysis. People living in such populated points consumed milk which was mixed from produce from different places. A typical example of this is the situation in the settlement Krasnaya Gora of Krasnogorsky district of Bryansk region. As was first noted in [9], the thyroid incorporated ^{131}I activity in the population of the indicated populated points is considerably above the activity predicted based on ^{137}Cs contamination density of 218 kBq/m^2. The reason was that the settlement Krasnaya Gora received milk from neighbouring heavily contaminated areas (to 2960 kBq/m^2 by ^{137}Cs) which was consumed by residents and this influenced the ^{131}I incorporated activity and hence absorbed thyroid dose.

The totality of presented data do not let us accept the hypothesis on relation of absorbed thyroid doses and ^{137}Cs contamination density in the populated points as a function (18), even without the strict approach described above. It should also be borne in mind that based on analysis of gamma-spectrometry of soil samples from Kaluga region [4], the correlation coefficient between ^{131}I and ^{137}Cs deposition density is about 0.7, which (taking into account what is said above) is also an argument for abandoning the hypothesis in question. We believe that methodologically it would be more appropriate to continue the work using all available data of ^{131}I measurements in 1986 to determine more

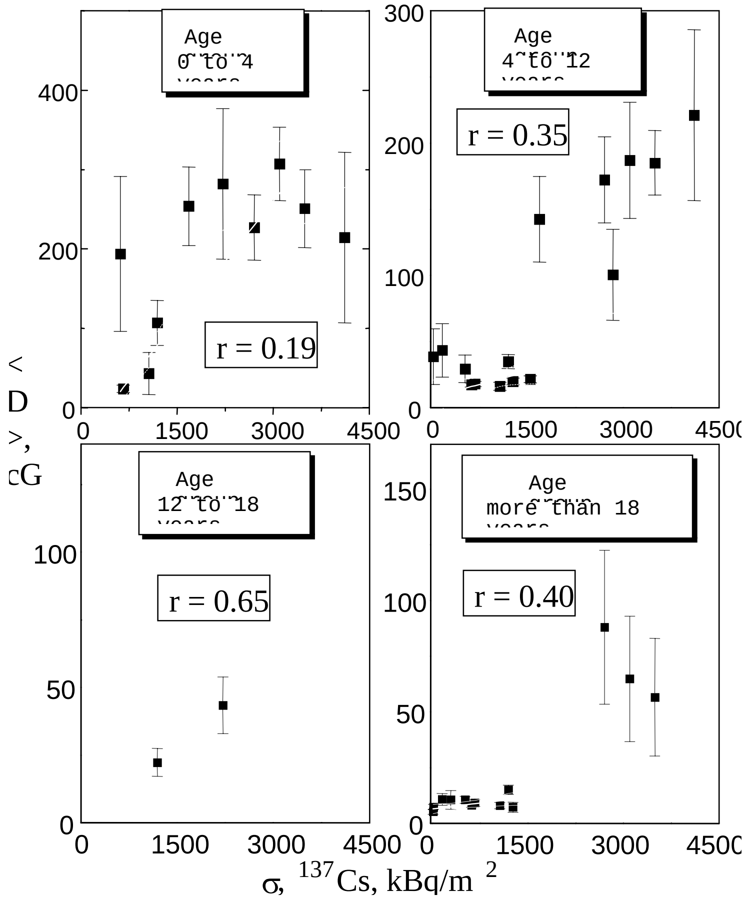


Fig. 14. A comparison of age absorbed thyroid doses < *D* > in residents of the contaminated areas of Bryansk region as a function of the ^{137}Cs contamination density *σ*. *r* is correlation coefficient between individual doses and the mean contamination density of ^{137}Cs.

accurately dynamics and density of ^{131}I depositions on the contaminated areas of CIS.

Conclusions

The space-time characteristics of formation of radioactive contamination is a factor of significance which should be taken into account in estimation of absorbed thyroid doses. The need for a new methodological approach to dose calculation based on retrospective reconstruction of dynamics of radioactive contamination has been confirmed quantitatively.

The verification of data of individual radiometry of residents of Bryansk region obtained in Bryansk oncological dispensary in May-June 1986 has shown that these data can be used for further estimation of absorbed thyroid dose.

The verification of data of individual thyroid dosimetry in residents of Kaluga region obtained by specialists of MRRC of RAMS in May-June 1986 using radiometers-dosimeters FSR-68-01 has demonstrated the necessity of introducing an adjustment which tends to reduce the earlier estimated activities of incorporated ^{131}I. The mean value of adjustment is about 0.1 μCi and it does not depend on age of a patient.

The mean absorbed thyroid doses in residents of some contaminated points of Bryansk region are higher those in Kaluga region by a factor of 5 to 15 in different age groups.

Based on the body of data of individual thyroid radiometry in residents of

Bryansk region we have failed to find quantitative confirmation to the hypothesis [9, 11] concerning a dependence like $D = a + b\sigma$, where D is mean thyroid dose; σ is ^{137}Cs soil contamination density; and a and b are constants.

In conclusion the authors express their sincere thanks to Prof. E.G.Matveenko, G.A.Davydov and B.Ya.Drozdovsky, heads of departments of MRRC of RAMS, G.E.Baleva, Bryansk oncological dispensary, Director of information-computer center of Health Department of Administation of Bryansk region B.G.Kvitko and head of laboratory of clinical dosimetry of Bryansk oncological dispensary V.N.Antropov for support in work, assistance in data collection and processing and members of Laboratory of radiation ecological informatics of MRRC of RAMS O.M.Klokova and T.I.Khvostunova for thorough work with the initial data.

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