Chernobyl Accident: Revision of individual Thyroid Dose Estimates for the Children included in the Cohort of the Belarusian-American Study

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The American-Belarusian epidemiological study is aimed at revealing the carcinogenic effectiveness of ^{131}I (the main contributor to the thyroid exposure) and at estimating the risk coefficient of thyroid disease, especially thyroid cancer, as a function of age at exposure. About 15,000 people who were 0-18 years old at the time of the accident will be observed for many years. They were selected out of about 40,000 children. Whose thyroid burdens were measured in May-June 1986. The initial thyroid dose estimates for the 40,000 children were performed on the basis of direct thyroid measurements. During these measurements personal interviews were not conducted.

As of August 1999, approximately 5,000 cohort subjects have been screened and interviewed. The initial estimates of individual thyroid dose are being revised for all of the cohort subjects that have been screened. The procedure for revision of the ^{131}I thyroid dose assessment consists of two parts: (1) re-analysis of the direct thyroid measurements and (2) analysis of the responses to the interview which were conducted in order to determine the kinetics of the radioiodine intake by the cohort subjects. Revised estimates of thyroid dose are presented for a sample of about 2,780 subjects residing in various areas of Belarus. The reason for the differences between the initial and the revised thyroid dose are discussed.

There are three minor contributors to the thyroid exposure besides ^{131}I. These are: (1) short-lived radioiodines and radiotelluriums, (2) other radionuclides (mainly radiocesiums taken into the body), and (3) radionuclides deposited on the ground that contributed external radiation exposure. Examples are provided to illustrate the relative importance of the 4 components of the thyroid dose.

BREIF DESCRIPTION OF THE COHORT STUDY

To date childhood thyroid cancer is the most significant health consequence of the Chernobyl accident for the population of Belarus. More than 1000 cases were observed amongst people who were 0 to 18 years old at the time of the accident. It is more then ten times more then the number of the detected cancers (21 cases in the age group of 0-18 years) during the yeatrs before the accident. It stimulated the initiation of a long-term Belarusian-American cohort study in 1994 (1).

The objective of this epidemiological study is to carry out assessments of the early and late morphologic and functional changes in the thyroid glands of persons exposed to radiation as a function of age at exposure. Numerous examinations of 15,000 subjects will be conducted for at least 20 years. The subjects were randomly selected from the group of approximately 40,000 persons who were children and adolescents at the time of the accident. All these persons lived in areas of Belarus that were contaminated by radioactive iodine released by the Chernobyl accident in 1986. Their thyroid exposure rates were measured during the first weeks after the accident. Initial estimations of the absorbed thyroid doses from ^{131}I were made on the base of these measurements.

INITIAL DOSE ESTIMATES

Several factors contributed to uncertainties in the measurements of ^{131}I in the thyroids of Belarusians in May-June 1986. Special studies were performed to assess factors important for dose estimation. The initial estimates of the absorbed thyroid doses were calculated using age-dependent functions describing radioiodine kinetics in the human body. The time variation of the ^{131}I intake rate was based on results of interviews conducted in 1988 (3).

The distribution of the initial estimates of the thyroid ^{131}I dose for individuals younger than 18 years old at the time of the accident is shown in Table 1.

Table 1. Distribution of the initial estimates of the thyroid doses from ^{131}I for persons whose thyroid radioactivity was measured

Age group	Dose interval, Gy			
	≤ 0.3	0.3–1.0	≥ 1	Total
0-3	3111	2047	2726	7884
4-6	3535	1941	1812	7288
7-9	3494	1899	1327	6720
10-14	5843	3391	1587	10821
15-18	4095	1818	874	6787
Total	20078	11096	8326	39500

NEW DOSE ESTIMATES

According to the study protocol the individual absorbed thyroid doses should be estimated based on the following components: internal exposure to ^{131}I, to short-lived radioiodines (^{132}I-^{135}I) and to ^{132}Te the precursor of ^{132}I; internal exposure to the other radionuclides (mainly radiocesium); and external exposure to ground deposition of radionuclides. Inclusion of these components provide a better estimate of the total thyroid doses for the cohort subjects.

Individual Interviews

Every individual coming for medical screening is interviewed to obtain information that is necessary for the thyroid dose estimation. The interview is designed to obtain detailed information on the location and behavior of the subject during the first weeks after the accident; on the sources and amounts of fresh milk and milk products, leafy vegetables, consumed during that time; and on the times (if any) of stable iodine intake. The dosimetry questionnaire, consists of 5 blocks of questions, which are shown in Table 2.

Table 2. List of dosimetry questionnaire topics.

No	Information requested
I.	**Personal Data** (last name at time of accident and at present, first name, patronymic, date of birth, sex, home address at time of accident and at present, telephone)
II.	**Information on habits and relocation** (date of evacuation or relocation, professional activities, time spent outdoors, type of residence)
III.	**Information on consumption of milk, milk products and leafy vegetables** (consumption rates, origin of consumed foodstuffs, date of changes in consumption)
IV.	**Iodine prophylaxis** (date when prophylaxis began, how many times, who conducted)
V.	**Medical exposure** (where, when, for which purposes)

The questions were prepared to help the individuals to remember details of their behavior after the accident. Because most cohort members were children at the time of the accident, a preliminary questionnaire was mailed to their homes to involve their parents in answering. The preliminary questionnaire also helps to prepare the subjects to respond more effectively at the time of the interview.

Presently approximately half of the cohort subjects have been interviewed and one third of them were interviewed for the second time in one or two years.

Direct Thyroid Measurements of Iodine-131

The following formula was used for calculation of the ^{131}I activity in the thyroid

$$A = CF \cdot (ER_{meas} - ER_{bgr}) \quad (1)$$

where: A is the ^{131}I activity in the thyroid;

CF is a calibration factor, Bq hr μR^{-1}, which depends upon the type of measuring device and the age of subject at the time of measurement,;

ER_{meas} is the exposure rate measured near the thyroid, μR hr^{-1};

ER_{bgr} is the background exposure rate, μR hr^{-1}.

An extensive study of the factors that may effect precision of the ^{131}I thyroidal activities measurement is conducted. The most promising method is simulation of the measurement conditions, using mathematical models of human body and detectors combined with Monte Carlo method of calculation (4). Factors that influenced the initial estimates of ^{131}I thyroidal activities are summarized in Table 3.

Table 3. Range of variation of the correction factors to be applied to the initial estimates of ^{131}I thyroidal activities, estimated in experiments (2) and Monte Carlo simulations (4).

Source of uncertainty	Range of variation of the correction factor
External radioactive contamination of the human body and/or of clothes	1 – 10
Internal contamination of the human body by $^{134,136,137}Cs$ and other radionuclides	1 – 3
Variation of the meter calibration factor as a function of the person's age, measurement conditions, and the type of instrument	1 – 2

Internal exposure assessment

Let us assume that there was a single radioactive fallout where the subject lived. The internal thyroid dose from β-γ-exposure of ^{131}I can be estimated as:

$$D = DF \cdot A \cdot F(t_m) \qquad (2)$$

here: $DF = E / m_{th}$ is an age-dependent dose factor per decay of ^{131}I, Gy;

E is average energy of β-γ radiation absorbed by the thyroid per a decay of ^{131}I, J;

m_{th} is thyroid mass, kg;

A is ^{131}I activity in the thyroid at the time of measurement, Bq;

$F(t_m)$ is a function that describes dynamics of ^{131}I intake and loss from the thyroid, s;

t_m is the time of measurement after the accident, day.

The values of parameters used for the initial dose estimates were taken from Cristy and Eckerman (5) and ICRP Publications 38,56 (6,7). Parameters values were interpolated to obtain 1-year average values.

The thyroid dose from short-lived radioiodines was calculated as a relative addition to the dose from ^{131}I. It was calculated using the following equation:

$$D_S / D_I = [D_g(^{131}I) / D_I] \cdot \sum_k (f_{gk} \cdot w_{gk}) + [D_h(^{131}I) / D_I] \sum_k (f_{hk} \cdot w_{hk}) \qquad (3)$$

here: D_S is the internal thyroid dose from all of short-lived radionuclides, Gy;

D_I is the internal thyroid dose from ^{131}I, Gy;

$D_g(^{131}I)$ and $D_h(^{131}I)$ are internal thyroid doses from ingestion and inhalation of ^{131}I, respectively, Gy;

$f_{gk} = DC_{gk}/DC_I$ is a ratio of dose coefficients for ingestion of radionuclide k and ^{131}I;

$f_{hk} = DC_{hk}/DC_I$ is a ratio of dose coefficients for inhalation of radionuclide k and ^{131}I;

$w_{gk} = IN_{gk}/IN_I$ is a ratio of ingestion amounts of radionuclide k and of ^{131}I;

$w_{hk} = IN_{hk}/IN_I$ is a ratio of inhalation amounts of radionuclide k and of ^{131}I.

The dose coefficients for short-lived radionuclides contributions were estimated with the help of data given in ICRP Publications 67, 71 and 72 (8,9,10). The inhalation of the short-lived to ingestion thyroid doses were estimated for different areas of Belarus. The lifestyle and behavior of the population during the first weeks after the accident were taken into account (11). The ratio of inhalation to ingestion doses was approximately equal to 20 for rural adults who did not reside in the 30-km zone. For the evacuated adults the ratio was considered to be equal to 9. For the urban population it was assumed that the inhalation dose is equal to the ingestion one. The dynamics of the short-lived radioiodines intake was considered to be the same as the ^{131}I. Let us assume that there was not iodine isotopes fractionation, and correction coefficient for tellurium is 0.7.

External exposure assessment

The following formula was used to evaluate the external thyroid doses from radionuclides deposited on the ground for the k-th age group of inhabitants during period of residence in a particular zone of radioactive contamination:

$$D_K = RF \cdot SF \cdot AF_k \cdot \sigma_{137} \int_{t_1}^{t_2} CF(t)dt, \qquad (4)$$

here D_k – the thyroid dose for a child from the k^{th} age group, Gy;

RF – a dose rate reduction factor that describes the local exposure as a comparative value to exposure in an undisturbed area;

SF – a dimensionless shielding factor that describes time spent indoors and the shielding provided by dwellings;

AF_k – the age correction factor for exposure of children in group k;

$\sigma_{137}(t)$ – ^{137}Cs ground deposition density at the time t, Bq m^{-2};

$CF(t)$ – the external thyroid dose rate caused by the radionuclides deposited on the ground at the time t, Gy yr^{-1} Bq^{-1} m^{2}.

t_1 and t_2 – the beginning and end of residence time in the contaminated zone, yr.

The factor $CF(t)$ defined as a dose rate in thyroid per unit of ^{137}Cs deposition density depends on age of a person, isotopic composition of fallout, and activity depth distribution in soil. A procedure described by Eckerman and Ryman (12) was used to estimate values of $CF(t)$. Assuming exponential distribution of activity in soil $CF(t)$ factors can be described as:

$$CF_i(t) = 3.15 \cdot 10^7 \cdot a_i(t) \cdot \sum_j Y_{i,j} \cdot \frac{1}{\beta(t)} \cdot \int_0^{\infty} PF(E_{i,j}, z) \cdot e^{-\frac{z}{\beta(t)}} dz \qquad (5)$$

where $3.15 \cdot 10^7$ is a conversion factor, s/yr;

$a_i(t)$ is a time-dependent ratio of nuclide i to ^{137}Cs activity in soil;

$E_{i,j}$ is energy of j^{th} line in emission spectrum of i^{th} nuclide;

$Y_{i,j}$ is quantum yield of j^{th} line in emission spectrum of i^{th} nuclide;

$\beta(t)$ is a parameter of exponential depth distribution, g cm^{-2};

$PF(E_{i,j},z)$ is a dose rate in an organ for a plane isotropic source of photons of energy $E_{i,j}$ in soil at depth z equal to mean free paths, Gy yr^{-1} per Bq m^{-2}.

External exposure of the population after the Chernobyl accident was mainly due to deposition of the gamma-emitting radionuclides ^{95}Zr, ^{95}Nb, ^{99}Mo, $^{103,106}Ru$, ^{110m}Ag, ^{125}Sb, $^{131m,132}Te$, $^{131,132,133,135}I$, $^{134,136,137}Cs$, ^{140}Ba, ^{140}La, $^{141,144}Ce$, ^{239}Np. All 21 radionuclides were taken into account for calculation of external thyroid dose.

The time dependence of the relaxation length, $\beta(t)$, was determined using the results of exposure rate measurements over unpolluted sites. At these locations, soil samples from different depths were taken and analyzed in the laboratory by gamma spectroscopy. It was found that an average migration velocity was $v = 0.18$ g cm^{-2} y^{-1}. This result coincides with that of Korneev et al. (13) for cesium deposited on the territory of Belarus. It was estimated that the initial relaxation length was 0.5 g cm^{-2} for wet and 0.2 g cm^{-2} and for dry depositions.

The empirical factor RF is used to show the reduction of dose rate observed in disturbed areas compared to that in an undisturbed area. A value of $RF = 0.7$ was obtained by Minenko et al. (14) by averaging data for areas located in radioactively contaminated regions of Belarus.

The shielding factor SF accounts for the dose reduction due to time spent indoors and seasonal variations of exposure rate. Ranges of the variation values for the products ($SF\ AF_k$) are 0.17-024 for urban and 0.28-0.40 rural children and adolescents.

Assessment of thyroid exposure to radiocesium in the body

A model based on the intake function was used to estimate the internal thyroid dose from ingested radiocesiums to the members of k^{th} age group constantly living in contaminated areas. The total internal dose from the radiocesium isotopes is given by:

$${}^{int}D_k = \sigma_{137} \cdot \sum_i DF_{k,i} \cdot \int_{t_1}^{t_2} I_{k,i}(t)dt, \qquad (6)$$

where $^{int}D_k$ is the thyroid dose from ingestion of ^{134}Cs and ^{137}Cs, Gy;
σ_{137} is the ground deposition density of ^{137}Cs, kBq m^{-2};
$DF_{k,i}$ is the thyroid dose coefficient for ingested i^{th} nuclide, Gy Bq^{-1};
$I_{k,i}(t)$ is normalized to ^{137}Cs deposition density the intake function of i^{th} nuclide for the members of k^{th} age group, Bq d^{-1} per kBq m^{-2};
t_1, t_2 are beginning and end of the activity ingestion time period, d.

Consumption of locally produced milk was the most important pathway for radiocesium ingestion for a significant part of the Belarusian population, (14). Therefore, the radioecological situation in a region can be characterized by the transfer factor k_m defined as the quotient of the concentration of ^{137}Cs in locally produced milk to the soil deposition density of that radionuclide at a given location. The territory of Belarus was divided into regions with low (less than 0.3 Bq L^{-1} per kBq m^{-2}), intermediate (0.3-1.0 Bq L^{-1}/ kBq m^{-2}) and high (more than 1.0 Bq L^{-1} per kBq m^{-2}) values of k_m.

The experimental data on concentrations of ^{137}Cs in milk were satisfactorily described by a sum of two exponential functions:

$$C_m(t) = a_{m,1} \cdot e^{-\lambda_{m,1} \cdot t} + a_{m,2} \cdot e^{-\lambda_{m,2} \cdot t}, \qquad (7)$$

here $C_m(t)$ is the normalized concentration of ^{137}Cs in milk (Bq L^{-1} per kBq m^{-2});
$a_{m,1}$, $a_{m,2}$ (Bq L^{-1} per kBq m^{-2}) and $\lambda_{m,1}$, $\lambda_{m,2}$ (d^{-1}) are parameters derived from the experimental data.
The optimal parameters' values obtained for the territories with different soil-to-milk transfer factors are given in Table 4.

Table 4. Parameters of the function $C_m(t)$.

Levels of the ^{137}Cs soil-to-milk transfer	$a_{m,1}$	$a_{m,2}$	$\lambda_{m,1}$	$\lambda_{m,2}$
	Bq L^{-1}/ kBq m^{-2}		d^{-1}	
Low transfer	2.6	0.01	1.34x10^{-3}	-5.9x10^{-4}
Intermediate transfer	3.6	0.37	1.32x10^{-3}	1.1x10^{-4}
High transfer	5.1	1.7	1.22x10^{-3}	5.4x10^{-5}

The ^{134}Cs intake was estimated from ^{137}Cs intake function regarding the initial ratio ^{134}Cs-to-^{137}Cs in the deposition was 0.52.

RESULTS AND DISCUSSION

Comparison of revised and initial ^{131}I dose estimations

A comparison of initial and revised thyroid doses from ^{131}I was made on a sample of 2,783 persons. The initial dose and age distributions of the individuals in that sample are shown in Table 5. They are similar to the distributions of direct measurements (see Table 1).

Table 5. Age and initial dose distribution of the members of the sample.

Age group	Dose interval, Gy			
	≤ 0.3	0.3 – 1.0	≥ 1	Total
0-1	34	49	155	238
1-2	31	58	187	276
2-7	226	206	599	1031
7-12	207	200	276	683
12-17	190	162	203	555
Total	688	675	1420	2783

A comparison of revised and initial doses is shown in Figure 1. The distribution of the ratio of revised and initial thyroid dose estimates, given in Figure 2, shows that the majority of the revised estimates are approximately equal to the initial ones; the median ratio is equal to 0.98. The range of the ratio is from 0.03 to 1. The maximum ratio was found for a subject who was actually exposed *in-utero*, but was considered to have been a child in the initial dose estimate.

The differences between the revised and the initial dose estimates are caused by:

a) changes in the date or place of relocation or in the date when the consumption of contaminated milk was stopped. For the initial estimates it was assumed that the date of relocation meant the end of radioiodine intake. Sometimes people were not relocated to a clean area but only to a less contaminated one. Therefore their ^{131}I intake was reduced but not eliminated;
b) taking into account information on iodine prophylaxis. The information on the stable iodine intake was not taken into account in the most of initial dose estimates;
c) taking into account dates of birth. Information on the exact date of birth was not included in the initial database.

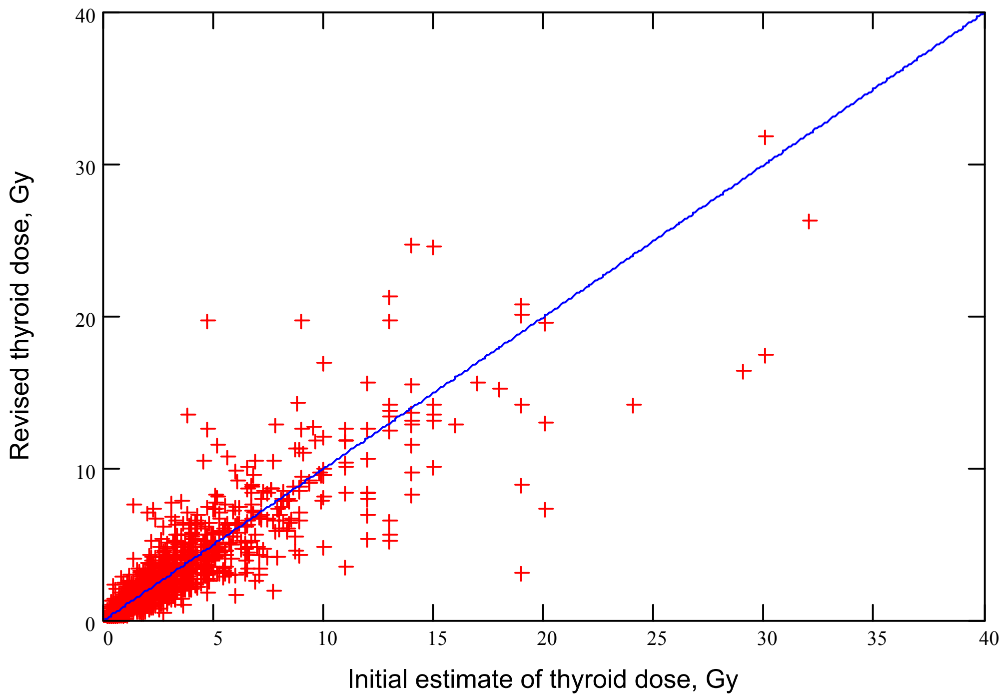

Figure 1. Revised vs. initial thyroid dose estimates for the members of the cohort.

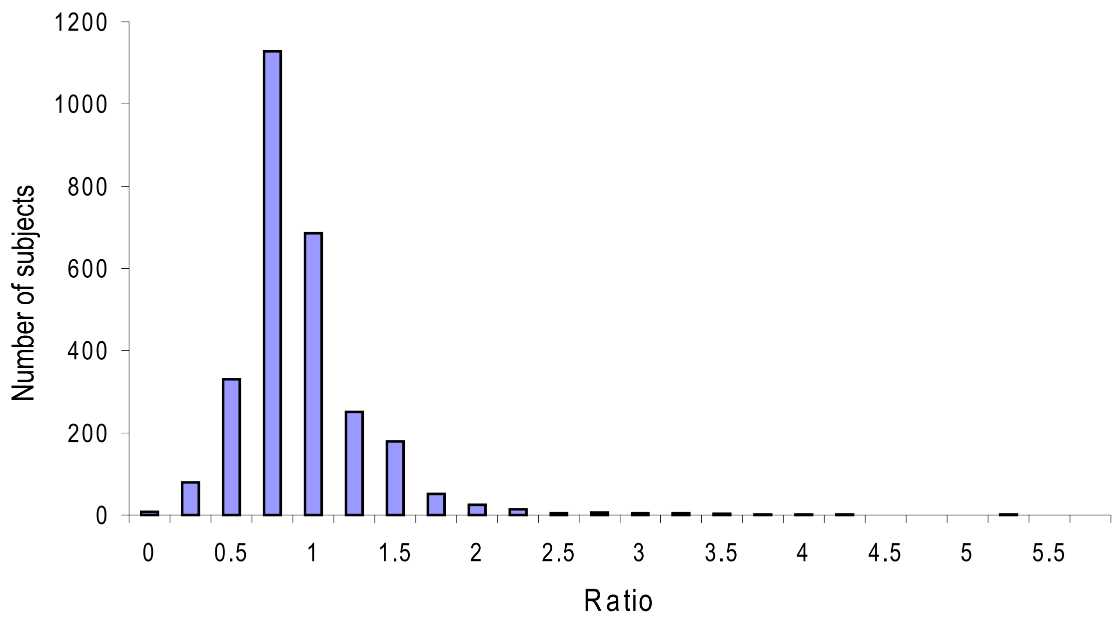

Figure 2. The distribution of the ratio of revised and initial thyroid dose estimates

The thyroid dose estimation process is not finished yet, as the reevaluation of the ^{131}I thyroidal activities based on the direct thyroid measurements is still in progress.

Thyroid dose from short-lived radioiodines

The relative contribution of short-lived radioiodines and ^{132}Te was estimated for different age-groups and different areas of Belarus (11). The contribution of short-lived radioiodines to thyroid dose is shown in Table 6. It was calculated for persons who consumed contaminated foodstuffs.

Table 6. Relative contribution of short-lived radionuclides to the thyroid dose

Region	Age-groups				
	3 mo.	1y	5y	10y	15y
Inside the 30-km zone	0.068	0.067	0.085	0.097	0.100
Outside the 30-km zone (southern raions of Gomel oblast)	0.028	0.028	0.036	0.040	0.041
Gomel-Mogilev cesium spot	0.017	0.019	0.032	0.043	0.045
Central raions of Belarus	0.015	0.015	0.019	0.022	0.023
Northern raions of Belarus	0.0032	0.0032	0.0039	0.0042	0.0042
city of Gomel	0.0076	0.0075	0.013	0.018	0.027
city of Mogilev	0.0038	0.0040	0.0093	0.014	0.022
city of Minsk	0.0041	0.0038	0.0047	0.0048	0.0061

The majority of cohort subjects consumed milk and milk products in the first weeks after the accident. The thyroid doses from short-lived iodines for these subjects were from 0.004 (for young children who lived in Minsk) to 0.1 of ^{131}I doses (for teens who were evacuated from the 30-km zone).

Thyroid dose from external irradiation

The thyroid doses from the external exposure to the radionuclides deposited on the ground were estimated for each subject on the basis of the ^{137}Cs deposition densities and the relative isotopic composition of the radioactive fallout at the locations where the subject spent a substantial amount of time. The external doses were calculated as cumulative doses over the period after Chernobyl accident. The dose distribution for cohort subjects is shown in Figure 3.

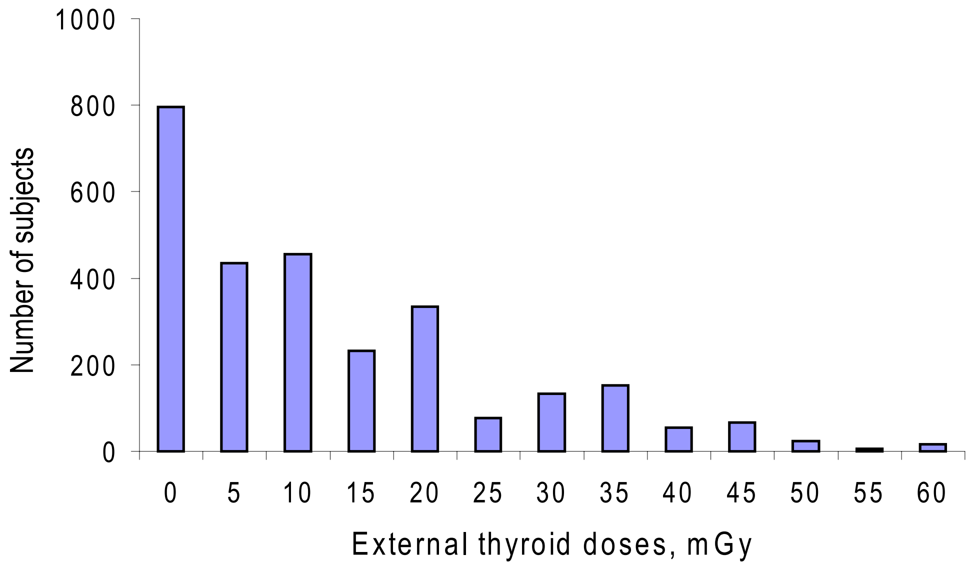

Figure 4. The distribution of the external thyroid dose estimates for the cohort member

The cumulative thyroid doses from external exposure ranged from 1.3 to 60 mGy. The smallest external doses were estimated for citizens of Minsk, and the highest external doses were calculated for evacuees from the 30-km zone.

Internal thyroid doses from radiocesium isotopes

The internal thyroid doses from consumption of foodstuffs contaminated with radiocesium isotopes were estimated taking into account personal data and consumption rates obtained from the questionnaires. The internal doses were calculated as cumulative values over the period after the Chernobyl accident. The distribution of internal doses from radiocesium for cohort subjects is shown on Figure 4.

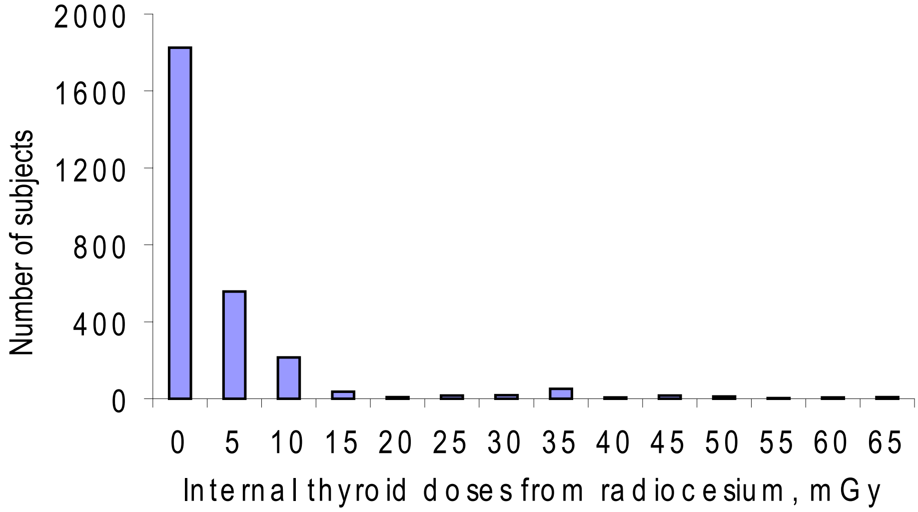

Figure 4. The distribution of the internal thyroid doses from radiocesium.

Cumulative internal thyroid doses ranged from 0.9 mGy to 67 mGy. The smallest internal doses were estimated for citizens of Minsk and the highest internal doses were calculated for inhabitants of the Narovlya raion.

The contributions to the total thyroid dose of the cohort subjects from external exposure and internal irradiation from radiocesiums were small. The sum of the contributions of short-lived radionuclides, external exposure, and radiocesium intakes to the thyroid dose is not greater than about 10% of the ^{131}I dose.

CONCLUSION

The methodology used to revise the individual thyroid doses received by the subjects of Belarusian-American cohort study includes contributions from four sources: internal exposure to ^{131}I; exposure to the short-lived radioiodines (^{132}I-^{135}I); and to ^{132}Te the precursor of ^{132}I; internal exposure to radiocesiums; and external exposure to 21 radionuclides deposited on the ground.

The most important contributor to the absorbed thyroid dose of the cohort subjects was ^{131}I. The contribution of short-lived radionuclides, external and internal exposure to all other radionuclides is not more than 10% of the thyroid dose caused by ^{131}I.

The correlation between the revised and initial dose estimates is generally good, but the dose differences for some individuals are rather high. One revised dose was 30 times smaller than the original estimate. At the other extreme, one revised dose was 7 times larger than the originally estimated value.

References

1. B.W. Wachholz. *United States Cooperation with Belarus and Ukraine in the Development and Implementation of Scientific Protocols of Thyroid Cancer and other Thyroid Disease following the Chernobyl Accident.* In Nagataki, S. (Ed.) “Nagasaki Symposium on Chernobyl Update and Future”. Elsevier Science B.V., 145-148 (1994).
2. Y.I. Gavrilin, K.I. Gordeev, V.K. Ivanov, L.A. Ilyin, A.I. Kondrusev, U.Y. Margulis, V.F. Stepanenko, V.T. Khrouch, S.M. Shinkarev, *The Process and Results of the Reconstruction of internal Thyroid Doses for the Population of contaminated Areas of the Republic of Belarus.* News Acad. Med. Sci. **2**:35-43 (1992).
3. Y.I.Gavrilin, V.T.Khrouch, S.M.Shinkarev, V.V.Drozdovitch, V.F.Minenko, E.V.Shemyakina, A.Bouville, L.Anspaugh, *Estimation of Thyroid Doses received by the Population of Belarus as a Result of the Chernobyl Accident*. In: The radiological consequences of the Chernobyl accident. Proceedings of the first international conference, Minsk, Belarus, 18 to 22 March 1996. EUR 16544 EN. Brussels, Luxembourg, 1011 – 1020 (1996).

4. A.V.Ulanovsky, V.F.Minenko, S.V.Korneev, *Influence of Measurement Geometry on the Estimate of ^{131}I Activity in the Thyroid: Monte Carlo Simulation of a Detector and a Phantom.* Health Phys. **71**:34-41 (1997).
5. M.Cristy, K.F.Eckerman, *Specific Absorbed Fractions of Energy at Various Ages from Internal Photon Sources.* ORNL/TM-8381/V1-7. Oak Ridge National Laboratory, Oak Ridge, (1987).
6. International Commission on Radiological Protection. *Radionuclide Transformations: Energy and Intensity of Emissions*. ICRP Publication 38. Oxford: Pergamon Press, (1983).
7. International Commission on Radiological Protection. *Age-dependent Doses to Members of the Public from Intakes of Radionuclides (Part 1).* ICRP Publication 56. Oxford: Pergamon Press; 1989.
8. ICRP (International Commission on Radiological Protection). *Age-dependent Doses to Members of the Public from Intakes of Radionuclides: Part 2 – Ingestion Dose Coefficients*. ICRP Publication 67. Pergamon Press, Oxford (1993).
9. ICRP (International Commission on Radiological Protection). *Age-dependent Doses to Members of the Public from Intakes of Radionuclides: Part 4 – Inhalation Dose Coefficients*. ICRP Publication 71. Pergamon Press, Oxford (1995).
10. ICRP (International Commission on Radiological Protection). *Age-dependent Doses to Members of the Public from Intakes of Radionuclides: Part 5 – Compilation of Ingestion and Inhalation Dose Coefficients*. ICRP Publication 72. Pergamon Press, Oxford (1996).
11. Yu.Gavrilin, V.Khrouch, S.Shinkarev, V.Minenko, E.Shemyakina, N.Luckyanov, P.Voilleque, *Assessment of the Thyroid Doses from the short-lived Radioiodines for the Population of Belarus according to two Scenarios of the Chernobyl Accident*. IRPA-2000, (2000).
12. K. F.Eckerman, J. C.Ryman, *External Exposure to Radionuclides in Air, Water, and Soil.* Federal guidance report No. 12. Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831 (1993).
13. S.Korneev, S.Tretyakevitch, V.Minenko, A.Ulanovsky, *External Exposure // Retrospective Dosimetry and Dose Reconstruction.* Final report ECP-10.— Brussels-Luxembourg, 104-110. — (EUR 16540 EN) (1996).
14. 14. V.F.Minenko, V.V.Drozdovitch, S.S.Tretiakevitch, A.V.Ulanovsky, *Exposure of Belarus Population after Chernobyl Accident: Collective Doses and Forecast of Stochastic Effects.* Medical and Biological Aspects of Chernobyl Accident, No.4, pp.50-65 (In Russian) (1996).