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ДОЗЫ ОБЛУЧЕНИЯ ЩИТОВИДНОЙ ЖЕЛЕЗЫ НАСЕЛЕНИЯ ПОСЛЕ ЧЕРНОБЫЛЬСКОЙ АВАРИИ

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Авария на Чернобыльской атомной электростанции (ЧАЭС) в Украине 26 апреля 1986 г. привела к выбросу радиоактивных веществ в атмосферу, в частности йода-131 (^{131}I), причем наибольшие выпадения этого радионуклида были в Беларуси, Украине и западной части России. Увеличение числа случаев рака щитовидной железы (ЩЖ) и других заболеваний ЩЖ среди облученного населения в этих странах стал основным медицинским последствием аварии на ЧАЭС. Поэтому большое внимание было уделено оценке доз облучения ЩЖ за счет поступления ^{131}I с продуктами питания в течение двух месяцев после аварии. В данной статье рассматриваются как индивидуальные дозы облучения ЩЖ для лиц, включенных в радиационные эпидемиологические исследования, так и средние дозы облучения для населения пострадавших стран. Индивидуальные дозы облучения ЩЖ от ^{131}I варьировали до 42 Гр и зависели от возраста человека, региона проживания на момент аварии и уровней потребления коровьего молока. Средние дозы облучения ЩЖ среди детей возраста 1 год достигли 0,75 Гр в наиболее загрязненной Гомельской обл. в Беларуси. Поступление ^{131}I было основным путем облучения ЩЖ: его средний вклад в дозу облучения составил более 90 %. Помимо облучения от ^{131}I, поступление короткоживущих изотопов йода (^{132}I, ^{133}I, ^{135}I) и теллура (^{131m}Te, ^{132}Te), внешнее облучение от гамма-излучающих радионуклидов, выпавших по поветхность почвы, и внутреннее облучения от ^{134}Cs, ^{137}Cs вносили вклад в дозу облучения ЩЖ, как правило, не более 10 %. Неопределенности, связанные с оценками доз, характеризуются в данной работе геометрическим стандартным

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отклонением распределения индивидуальных стохастических доз, которое варьировалось в среднем от 1,6 для доз, основанных на измерениях активности ^{131}I в ЩЖ, до 2,6 для доз, рассчитанных с использованием дозиметрических моделей. С радиологической точки зрения, ^{131}I был наиболее важным радионуклидом, воздействие которого привело к росту случаев рака ЩЖ среди населения, облученного после аварии на ЧАЭС.

Ключевые слова: Чернобыль; щитовидная железа; радиация; облучение; ^{131}I.

THYROID DOSES OF THE POPULATION AFTER THE CHERNOBYL ACCIDENT

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The accident at the Chernobyl nuclear power plant (NPP) in Ukraine on 26 April 1986 resulted in a significant release of radioactivity to the atmosphere, particularly of Iodine-131 (^{131}I), with the greatest contamination occurring in Belarus, Ukraine, and western part of Russia. Increase in thyroid cancer and other thyroid diseases incidence in exposed population in these counties was the main health consequence of Chernobyl accident. Therefore, much attention was paid to the thyroid doses, mainly due to the ^{131}I intake with foodstuffs during two months after the accident. This paper reviews the thyroid doses received by the population of the affected countries, both individual doses for subjects of radiation epidemiological studies and average doses for the population. Individual thyroid doses due to ^{131}I intake varied up to 42 Gy and depended on the age of the person, region of residence at the time of the accident and cow's milk consumption habits. The population-average thyroid doses among young children reached 0.75 Gy in the most contaminated area, Gomel Oblast, in Belarus. Intake of ^{131}I was the main exposure pathway to the thyroid gland: its average contribution to the thyroid dose was more than 90 %. In addition to exposure from ^{131}I, the intake of short-lived radioiodine (^{132}I, ^{133}I, ^{135}I) and radiotellurium (^{131m}Te, ^{132}Te) isotopes, external irradiation from gamma-emitting radionuclides deposited on the ground, and ^{134}Cs, ^{137}Cs ingestion contributed to the thyroid doses, typically, not more than 10 %. Uncertainties associated with dose estimates, in terms of mean geometric standard deviation of individual stochastic doses, varied in range from 1.6 for doses based on individual-radiation measurements to 2.6 for 'modelled' doses. From a radiological point of view, ^{131}I was the most important radionuclide that caused radiation exposure to the thyroid gland after the Chernobyl accident and an increase in the incidence of thyroid cancer and other thyroid diseases among the exposed population.

Keywords: Chernobyl; thyroid; radiation; exposure; ^{131}I.

Introduction

The Chernobyl accident led to widespread radioactive contamination in many countries of the northern hemisphere, particularly in Belarus, Ukraine, and the western part of Russia. The accident resulted in the release from the damaged reactor of a large amounts of radionuclides into the atmosphere, including the radiologically significant short-lived (SL) ^{131}I, ^{132}Te, ^{133}I and longer-lived gamma-emitting radionuclides, including ^{134}Cs, ^{137}Cs [1].

The increase of thyroid cancer (TC) among persons who were exposed to Chernobyl fallout during childhood and adolescence were reported a few years after the accident in Belarus, Ukraine and Russia [2–4]. A number of radiation epidemiology studies suggested that an increased risk of TC and other thyroid diseases associated with the thyroid exposure to ^{131}I [5–9]. The results of these and other studies carried out among the affected population [10–12] suggested also that an increase in the incidence of TC in individuals exposed in childhood and adolescence was the main health effect of the Chernobyl accident. The excess odds ratios (EOR) of radiation-related TC derived in these cohort and case–control studies were similar within the range of uncertainties and varied from 1.36 Gy^{-1} (95 % confidence interval (CI): 0.39–4.15) [8] to 8.4 Gy^{-1} (95 % CI: 4.1–17.3) [11]. An increased risk of TC, but not statistically significant, (EOR/Gy = 3.91, 95 % CI: –1.49, 65.7) has been reported in individuals exposed to Chernobyl fallout *in utero* [13].

Since the main health effect of the Chernobyl accident is an increase in the incidence of TC and other thyroid diseases, the greatest attention was paid to the assessment of thyroid doses. The main purpose of this paper is to summarize the results of reconstruction of the thyroid doses of the population exposed to the Chernobyl accident.

Thyroid doses: general considerations

After the Chernobyl accident, the radiation absorbed dose to the thyroid gland for the members of the public resulted mainly by the ^{131}I intake. In brief, the radionuclides, which were released into atmosphere during the accident, deposited on the ground surface and contaminated the pasture grass covering the ground. The grazing cows ate the contaminated grass and fraction of the radioactivity was transferred to their milk. The consumption of fresh cow's milk contaminated with ^{131}I was the main pathway of thyroid exposure while the inhalation of contaminated air playing a minor role. The radiation dose due to ^{131}I intake is the highest for the thyroid gland as iodine accumulates in this organ. Thyroid doses in children are higher than that of adults is because of the smaller size of the thyroid in children. Since the half-life of ^{131}I is 8.02 days, radiation exposure to the thyroid gland occurred during the first two months after the accident when the activity of ^{131}I in the environment became negligible.

In addition, there were other contributions to the thyroid dose, which were typically quite small for most people, but relatively important for individuals with no or little milk consumption: (1) internal irradiation resulting from intake of SL radioiodine isotopes (^{132}I, ^{133}I, and ^{135}I) and radiotellurium isotopes (^{131m}Te and ^{132}Te); (2) external irradiation from gamma-emitting radionuclides deposited on the ground; and (3) ingestion of ^{134}Cs and ^{137}Cs.

There are two types of doses to the population:

– An individual dose for a specified person that considers (i) information on individual whereabouts and consumption history collected, typically, by means of personal interview and (ii) individual-based radiation measurements, if available; and

– A population-average dose for an unspecified individual that is estimated using generic values of dosimetry models.

Estimates of individual dose are required for radiation epidemiological studies while the population-average doses are used for the purposes of radiation protection by comparing of exposure levels in population groups of different ages living in different territories. Radiation thyroid doses are also classified as 'measurement' doses, which are estimated using individual-based radiation measurements, and 'modelled' doses, which are estimated using dosimetry models.

The following information was available to reconstruct radiation doses to the population in Belarus, Ukraine, and Russia:

– About 400,000 measurements of ^{131}I thyroidal activity that were derived from gamma radiation using detectors placed against the neck (called 'direct thyroid measurements') made shortly after the accident among the population resided in contaminated areas [14–16]. The measurement results were used to assess individual thyroid doses from ^{131}I intake.

– Deposition density of ^{137}Cs measured in nearly every settlement in the contaminated areas [17].

– Deposition densities of ^{131}I and other radionuclides, such as ^{95}Zr, ^{95}Nb, ^{103}Ru, ^{106}Ru, ^{140}Ba, ^{140}La, ^{141}Ce and ^{144}Ce, measured in some settlements [18–20].

– ^{131}I, ^{134}Cs and ^{137}Cs activity concentrations derived from measurements of total beta-activity in cow's milk [21; 22].

– Thyroid volume measurements carried out in the early 1990s by the Sasakawa Memorial Health Foundation [23–25].

Thyroid doses from intake of ^{131}I

Individual thyroid doses for the subjects of radiation epidemiological studies

The most reliable individual thyroid doses were estimated based on the results of measurements of the ^{131}I thyroid activity done between 26 April and 30 June 1986 in the most contaminated oblasts in Belarus, Ukraine and Russia. There are two cohort studies that used estimates of individual ^{131}I thyroidal activity measured for all cohort members and evaluated the uncertainties in doses. These two thyroid screening cohorts consist of 11,732 and 13,204 individuals in Belarusian-American (BelAm) cohort and Ukrainian-American (UkrAm) cohort, respectively, selected from people who were 0–18 y old at the time of the Chernobyl accident [26]. The Belarusian-American cohort includes persons who resided at the time of the accident in Gomel and Mogilev Oblasts as well as in the city of Minsk; the Ukrainian-American cohort consists of residents of Chernihiv, Kyiv and Zhytomyr Oblasts the most contaminated regions in Belarus and Ukraine after the Chernobyl accident. Fig. 1 shows the scheme of the thyroid dose calculation for the cohort members.

In brief, the transfer of ^{131}I from the ground deposition to the thyroid gland via the activity intake due to inhalation of air and ingestion of foodstuffs was evaluated by use of ecological and biokinetic models and personal interview data on individual residential history and consumption. For each cohort member, two thyroid doses were calculated: (i) a '*model*-based' thyroid dose, D_{model}, based on the time-integrated ^{131}I activity in the thyroid that was calculated using ecological and biokinetic models, and (2) a '*measurement*-based' thyroid dose, D_{meas}, based on the calibration of *model*-based dose using the ^{131}I thyroid activity measured at time t_m after the accident, $Q_{meas}(t_m)$. The *measurement*-based thyroid dose estimate is more reliable than the *model*-based dose estimate because it was based on the measured ^{131}I thyroid activity.

Information on the person's whereabouts, consumption of fresh cows' milk, cows' milk products, and leafy vegetables as well as the administration of stable iodine necessary for the assessment of the individual thyroid doses was collected by means of personal interviews during two screening cycles in each cohort [27; 28]. Another two screening thyroid cohorts consist of persons exposed *in utero*, 2,965 and 2,582 individuals in Belarus and Ukraine, respectively [29; 30]. A fraction of the cohorts' members, around 10 % in Belarus and 28 % in Ukraine, was subject to direct thyroid measurements [31; 32]. Essentially the same approach was used to calculate thyroid doses due to ^{131}I intake for members of Belarusian-American and Ukrainian-American cohorts as well as for the Belarusian and Ukrainian *in utero* cohorts.

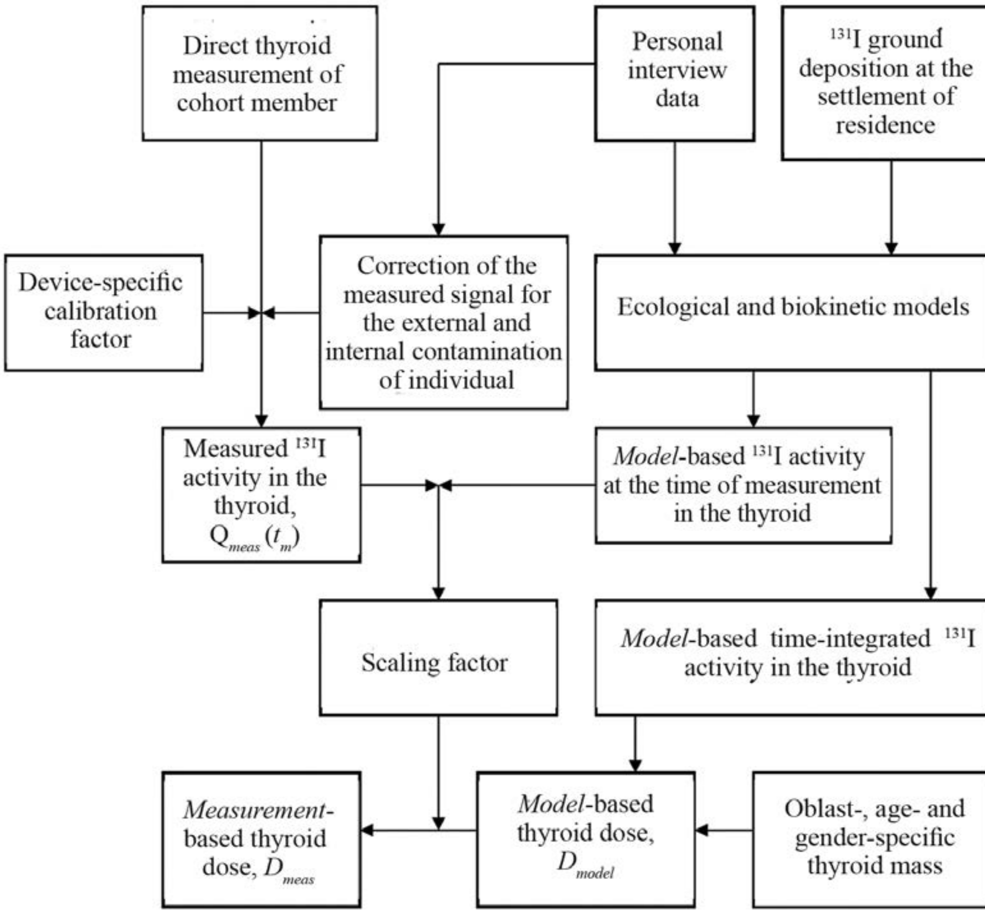

Fig. 1. Scheme of thyroid dose calculation for the cohort members

Table 1 shows the distribution of thyroid doses due to ^{131}I intake in these four cohorts. More than 2/3 of the subjects of the Belarusian-American and Ukrainian-American cohorts received thyroid doses less than 0.5 Gray (Gy) and of the Belarusian and Ukrainian *in utero* cohorts received thyroid doses less than 0.05 Gy. Individual thyroid doses varied widely from essentially 0 to 39, 42, 15 and 2.7 Gy in the BelAm, UkrAm, Belarusian *in utero* and Ukrainian *in utero* cohorts, respectively (not shown).

Table 1

Distribution (%) of subjects of the screening cohorts in Belarus and Ukraine according to the thyroid doses from ^{131}I intake

Thyroid dose (Gy)	Belarusian cohort[a] [33]	Ukrainian cohort[a] [28]	Belarusian *in utero* cohort[b] [31]	Ukrainian *in utero* cohort[b] [32]
<0.05	16.9	18.1	67.3	70.7
0.05–0.199	25.6	32.9	18.4	19.5
0.2–0.499	24.0	21.4	9.2	6.3
0.5–0.99	15.9	12.3	3.3	2.0
1.0–4.99	15.9	13.4	1.6	1.5
5–9.99	1.3	1.3	0.2	–
≥10	0.4	0.6	0.03	–

Note. [a]Distribution is shown for arithmetic mean of 1,000 *individual stochastic* doses, see below. [b]Prenatal thyroid dose.

In the Belarusian-American and Ukrainian-American studies the thyroid doses were calculated in a stochastic mode using a Monte-Carlo simulation procedure to provide an estimate of the uncertainties [28; 33]. In accordance with this procedure, 1,000 *individual stochastic* thyroid doses due to ^{131}I intake were calculated with accounting to the sources of shared and unshared errors. Fig. 2 shows, as example, the general scheme of calculation of 1,000 sets of the Belarusian-American cohort doses and *individual stochastic* thyroid doses.

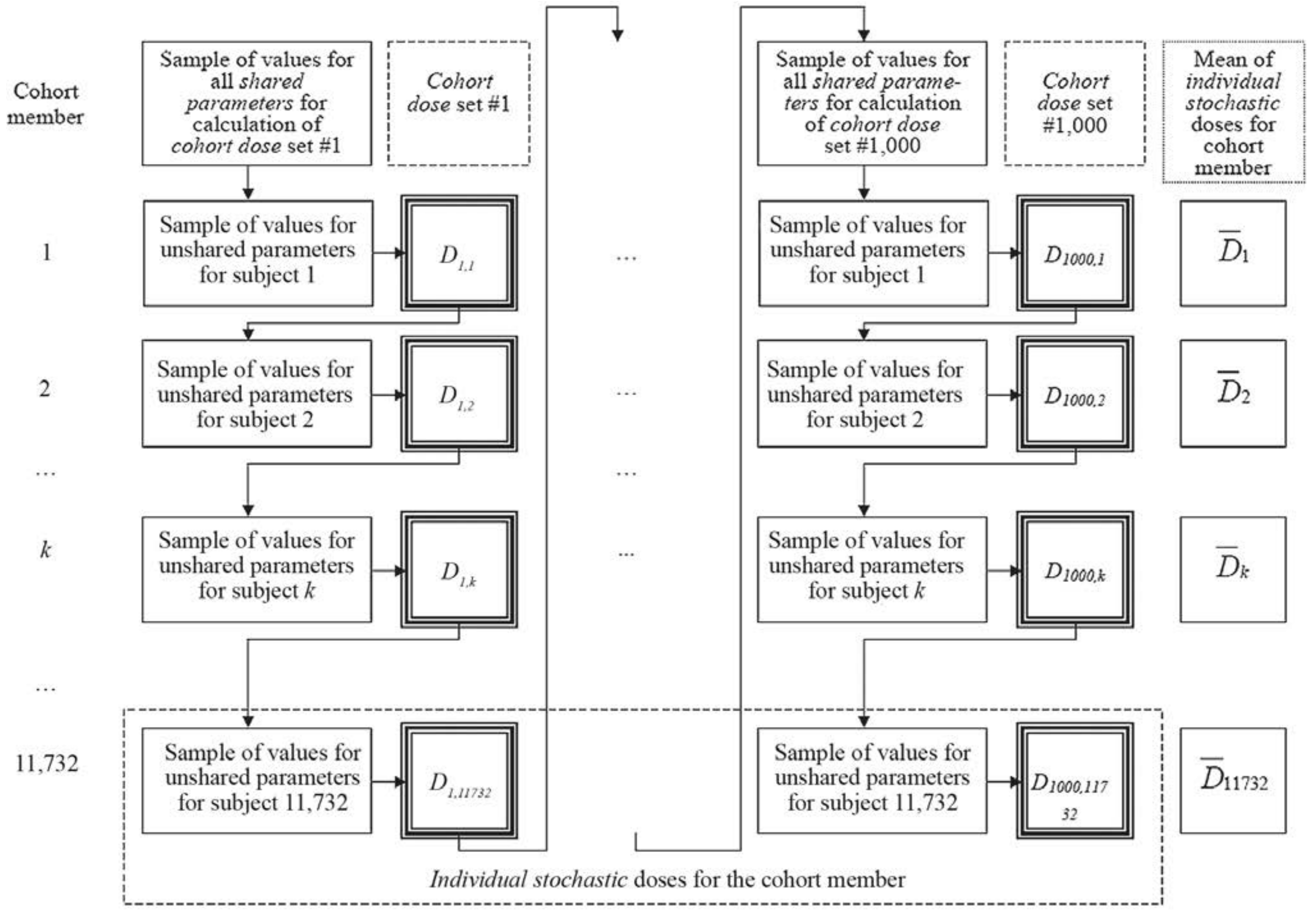

Fig. 2. General scheme of calculation of 1,000 sets of cohort doses considering shared and unshared errors [33]

At the beginning of the calculation of each dose set for the entire cohort, values for all shared parameters were assigned. The same value for each shared parameter was used to calculate one dose set for all cohort members for whom this parameter was shared, e. g., ^{131}I deposition density in the settlement was shared among all individuals who resided in that settlement. This step introduced correlations in each cohort dose set between individual dose estimates of the study subjects who shared parameters' values. In process of dose set simulation, values of unshared parameters for each cohort member were sampled from their distributions and calculated one dose realization for cohort member k, $D_{i,k}$. Set of doses from $D_{i,1}$ to $D_{i,N}$ represents set number i of *cohort* thyroid doses for N cohort subjects. The thousand realizations of dose across the cohort dose sets for cohort member k, represent the *individual stochastic* thyroid doses of that cohort member.

The fitted distribution of 1,000 *individual stochastic* doses for cohort members was approximately lognormal and the geometric standard deviation (GSD) of this distribution was used to characterize the overall uncertainty. The GSDs of individual stochastic doses varied from 1.3 to 5.1 with an arithmetic mean of 1.8 and a geometric mean of 1.7 for the subjects of the Belarusian-American cohort, and from 1.3 to 10.6 with an arithmetic mean of 1.6 and a geometric mean of 1.5 for the subjects of the Ukrainian-American cohort. The uncertainties in thyroid doses were driven by sources of unshared classical errors associated with the derivation of ^{131}I activity in the cohort member's thyroid from direct thyroid measurements and with the estimates of thyroid-mass values [28; 33].

If the result of measurement of ^{131}I thyroidal activity was not available for the individual, thyroid doses for the subjects of radiation epidemiological studies were estimated using two types of models:

– Purely empirical models based on the correlation between environmental contamination (^{137}Cs or ^{131}I deposition density, ^{131}I concentration in milk) and thyroid doses derived from direct thyroid measurements done among individuals of different ages (e. g., [15; 21; 34–36]); and

– The environmental transfer model considered the multi-compartment process of ^{131}I activity transfer to the human thyroid either from ^{131}I deposition leading to contamination of milk and leafy vegetables for ingestion or/and from ^{131}I concentration in ground-level air for inhalation (e. g., [37–39]).

To assess the individual modelled thyroid doses, a personal interview was conducted with study subjects or their relatives to collect information on the whereabouts and consumption history for a given person.

Table 2 presents, as example, the thyroid doses due to ^{131}I by age and by country of residence among the subjects of the case-control study of TC in Gomel and Mogilev Oblasts in Belarus and Bryansk, Kaluga, Orel and Tula Oblasts in Russia, which was coordinated by International Agency for Research on Cancer (IARC). Data from the table show that the thyroid dose decreased with increasing age as thyroid mass decrease with increasing age. The mean thyroid dose for the study subjects from Russia was estimated to be more than five times lower than that for the subjects from Belarus, i. e., 0.10 Gy *vs*. 0.54 Gy. The GSDs of *individual stochastic* doses estimated in this study varied from 1.6 to 3.6 with an arithmetic and geometric means of 1.9 over all subjects.

Table 2

Thyroid doses due to ^{131}I intake at different ages and by country of residence among subjects of the case-control study of TC in Belarus and Russia [40]

Age (y)	Thyroid dose[a] (Gy)	
	Belarus	Russia
<2	0.70	0.43
2–4.9	0.51	0.14
5–9.9	0.38	0.033
10–14.9	0.19	0.021
15–18	0.20	0.020

Note. [a]Arithmetic mean of 1,000 *individual stochastic* doses.

Fig. 3 shows the cumulative distribution of 1,000 sets of doses estimated in a case-control study of TC. Wide distribution (the range of medians across alternative dose realization was 0.063–0.22 Gy) indicates that the uncertainties in thyroid doses for the study subjects were driven by the shared (Berkson) errors associated with parameters of the dose reconstruction model [40].

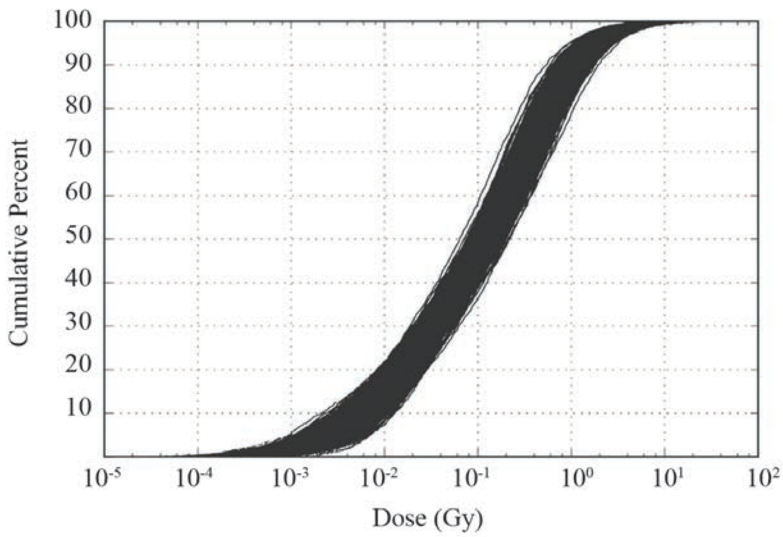

Fig. 3. Cumulative percentage of 1,000 sets of doses for a case-control study of TC [40]

Table 3 provides a summary of the thyroid doses from ^{131}I intake estimated in in the post-Chernobyl radiation epidemiology studies conducted in Belarus, Ukraine, and Russia in which measurements of ^{131}I thyroidal activity were not available for each study subject.

Table 3

Summary of the thyroid doses from ^{131}I intake estimated in the post-Chernobyl radiation epidemiology studies conducted in Belarus, Ukraine, and Russia

Study	N of subjects	Thyroid dose from ^{131}I (Gy)			Reference
		Mean	Median	Range	
Persons exposed *in utero* [a]					
Belarusian *in utero* cohort study	2,965	0.13	0.017	0–15	[31]
Ukrainian *in utero* cohort study	2,582	0.087	0.017	0–2.7	[32]
Genomic study of TC in Belarus	157	0.13	0.032	0–4.5	[41]
Persons exposed during childhood					
Case-control study of TC in Belarus	321	0.30	0.11	0–4.3	[42]
IARC case-control study of TC[b]	1,695	0.54	0.29	3.0×10^{-4}–8.7	[40]
Case-control study of TC in Russia	198	–	0.044/0.016[c]	0–2.7	[35]
The Chernobyl Tissue Bank[d]	1,869	0.24	–	1.0×10^{-3}–24	[43]
Genomic study of TC in Belarus	1,884	0.23	0.088	0–9.0	[41]

Note. [a] The sum of prenatal and postnatal thyroid doses. [b] The study participants from Belarus. [c] Cases/controls. [d] The study participants from Ukraine.

Population average dose estimates

Thyroid doses from ^{131}I intake for population sub-groups were estimated using a combination of the methods indicated above. The following groups of population were considered [44; 45]: evacuees from the 30-km zone around Chernobyl NPP and residents of the contaminated areas in the most affected countries, Belarus, Ukraine, and Russia.

Evacuees. More than 100,000 persons were evacuated in the weeks after the accident from the most contaminated 30-km zone around Chernobyl NPP in Ukraine and Belarus. The thyroid doses varied with place of residence, date of evacuation, and the age of the evacuees. Evacuees from Belarusian villages received the highest doses, the average thyroid dose was estimated to be 0.68 Gy for adults and 3.1 Gy for young children (0–7 y) *vs*. 0.28 Gy and 1.2, respectively, for evacuees from Ukrainian villages [44]. The thyroid doses for the evacuees from the town of Pripyat were 0.28 Gy for adults and 0.99 Gy for young children received mainly due to the ^{131}I intake with cow's milk during their stay in the villages where they were evacuated [46]. For the entire evacuated population, the population-weighted average thyroid dose was 0.47 Gy. It should be noted that thyroid doses were estimated based on direct thyroid measurements that were done among evacuated persons.

Residents of the contaminated areas. Table 4 gives the thyroid doses due to ^{131}I intake for the populations of Belarus, Ukraine, Russia and other European countries [1; 47].

Population-average thyroid doses depended on the dates of fallout and the levels of ^{131}I ground deposition, which varied from region to region, and on the dates when pasture grazing season started, since cow's milk was the main source of ^{131}I intake to the exposed population. The highest oblast-average thyroid dose due to ^{131}I intake among the three countries was realized in the most contaminated Gomel Oblast in Belarus, it varied from 0.15 Gy for adults to 0.75 Gy for youngest children. The highest dose in Ukraine was found in Zhytomyr Oblast, 0.06 Gy for adults and 0.23 Gy for children 0–7 y old; and in Russia in Bryansk Oblast, 0.026 Gy for adults and 0.16 Gy for children 0–7 y.

Thyroid doses from pathways other than intake of ^{131}I

Thyroid doses for most individuals were mainly defined by exposure from ^{131}I intake. Other exposure pathways were usually minor contributors to the thyroid dose: (1) intake of SL radionuclides, ^{132}I, ^{133}I, ^{135}I, ^{131m}Te, and ^{132}Te; (2) external irradiation from gamma-emitting radionuclides deposited on the ground, mainly ^{132}Te+^{132}I, ^{140}Ba+^{140}La, and ^{95}Zr+^{90}Nb in the short term and ^{137}Cs in the long term; and (3) intake of ^{134}Cs and ^{137}Cs with locally produced foodstuffs. The methods, which were used to estimate thyroid doses from minor exposure pathways, are described elsewhere [42, 48–50]. Table 5 shows the contribution of minor exposure pathways to the individual thyroid doses for the subjects of epidemiological studies.

Table 4

Population average thyroid doses from ^{131}I intake in Belarus, Ukraine, Russia and other European countries [1; 47]

Country, oblast	Population	Thyroid dose (Gy) for	
		children 0–7 y	adults
Belarus			
– Brest Oblast	1,408,000	0.12[a]	0.026
– Vitebsk Oblast	1,410,000	0.007[a]	0.0020
– Gomel Oblast	1,651,000	0.75[a]	0.15
– Grodno Oblast	1,154,000	0.028[a]	0.0058
– Minsk Oblast	1,587,000	0.016[a]	0.0047
– Minsk City	1,518,000	0.10[a]	0.018
– Mogilev Oblast	1,280,000	0.13[a]	0.031
Ukraine			
– Chernihiv Oblast	1,416,000	0.15	0.037
– Kyiv Oblast	1,685,000	0.20	0.053
– Kyiv City	2,565,000	0.094	0.024
– Zhytomyr Oblast	1,548,000	0.23	0.060
Russia			
– Bryansk Oblast	1,473,000	0.16	0.026
– Kaluga Oblasts	1,041,000	0.013	0.002
– Orel Oblasts	863,000	0.058	0.009
– Tula Oblasts	1,863,000	0.044	0.006
Latvia	2,667,000	0.0051[a]	0.0015
Lithuania	3,684,000	0.023[a]	0.0043
Poland	37,960,000	0.0078[a]	8.0×10^{-4}
Rest of Europe	~440,000,000	8.0×10^{-6} – 0.021[a]	2.0×10^{-6} – 0.0063

Note. [a]For 1-y age group according to [47].

Table 5

Mean contribution of minor exposure pathways to the individual thyroid dose among the subjects of epidemiological studies [31; 33; 50; 51]

Pathway	Mean contribution (%) of minor exposure pathways to the individual thyroid dose among the subjects of the study				
	Belarusian-American cohort [33]	Belarusian *in utero* cohort[a] [31]	Case-control study [50]	Case-control study [51]	
	Belarus	Belarus	Belarus	Belarus	Russia
Intake of SL radionuclides[b]	2.0	–[c]	2.0	1.6	0.7
External irradiation	4.5	3.6	1.8	3.4	6.3
^{137}Cs ingestion	1.5	1.8	1.0	1.3	2.3
All minor exposure pathways	8.0	5.4	4.8	6.3	9.3

Note. [a]Prenatal thyroid dose. [b]SL radioiodine (^{132}I, ^{133}I, ^{135}I) and radiotellurium (^{131m}Te, ^{132}Te) isotopes. [c]Not considered.

The mean contribution of the minor pathways to the total thyroid dose varied from 5 to 8 % for subjects of the studies conducted in Belarus and was about 10 % for subjects in Russia. However, the contribution of minor pathways may be substantial for some individuals. For evacuees from Pripyat-town, the contribution of SL radionuclides (^{132}I, ^{133}I, and ^{132}Te) was about 30 % of the total thyroid dose due to inhalation [52]. Another study estimated that for 19 out of 1,615 (1.3 % of the total) study participants, the contribution of prolonged sources of exposure to the thyroid dose was higher than 50 % [51]. These individuals were relocated from contaminated residents shortly after the accident or did not consume locally produced foodstuffs and, therefore, received relatively small doses from ^{131}I intake occurred during the first two months after the accident, but were exposed to high doses from external irradiation and ^{134}Cs, ^{137}Cs ingestion in subsequent years.

Conclusions

This paper considers the radiation exposure to the thyroid after the Chernobyl accident. The most important radiological consequence of the accident was exposure to ^{131}I, which led to an increase in the rate of TC and other thyroid diseases in the exposed population. The thyroid doses were mainly defined by the consumption of ^{131}I-contaminated cow's milk. Individual thyroid doses due to ^{131}I intake varied up to 42 Gy and depended on the age of person, the region where people were exposed, and their cow's milk consumption habits. In addition to exposure from ^{131}I, the intake of SL radionuclides, external irradiation from gamma-emitting radionuclides deposited on the ground, and ^{134}Cs, ^{137}Cs ingestion contributed to the thyroid doses, typically, not more than 10 %.

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