Iodine-131 Contamination, Thyroid Doses and Thyroid Cancer in the Contaminated Areas of Russia

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Abstract

About 1,800 PBq of I-131 was deposited in the environment as a result of the Chernobyl accident. The most contaminated territories in Russia are located in Bryansk, Tula, Orel and Kaluga regions. About 80% of total I-131 deposition was formed during the first week after the accident. Direct measurements of deposition densities of I-131 were very limited as far as this radionuclide decayed very fast (with half time about 8 days). In contrast, Cs-137, which is long-lived radionuclide, was investigated much more extensive. As a result all available information about the ratio of I-131 to Cs-137 has been used to estimate deposition densities of I-131 for the purpose of thyroid dose estimation. The results of direct measurements of radioactive iodine content in human thyroid gland together with the available data on I-131 and caesium-137 contamination of the soil were used for development of semi-empirical model for reconstruction of thyroid absorbed doses in cases when the measurements were not performed in 1986.

According to the estimations, which are based on the results of direct measurements of I-131 activity in thyroid (Kaluga and Bryansk regions), the median of individual thyroid dose values in Kaluga region (7 districts) varies from 30 mGy for children to 8 mGy for adults. In Bryansk region (5 districts) the median dose values for adults are in the range from 140 mGy to 30 mGy. Collective thyroid doses over the territories where the density of Cs-137 soil contamination exceeded 3.7 kBq/m^2 (0.1 Ci/km^2) in the most contaminated 4 regions were estimated to be 72,600, 16,900, 13,400 and 3,400 person-Gy for Bryansk, Orel, Tula and Kaluga regions, respectively.

The data on annual thyroid cancer morbidity over 1986-2000 years in residents of the most affected Bryansk region, aged 0-50 years at the moment of the accident, is also presented. During the first five years after the accident (1986-1990) annual thyroid cancer morbidity in different age groups (0-4 years, 5-9, 10-14, etc.) remained at quite stable levels. Since 1991 a stable increase of the number of thyroid cancer in all age groups of the studied population has started. The semi-empirical model was applied to reconstruct individual thyroid dose for 26 thyroid cancer cases (0 - 18 years old at the moment of the accident) in the most contaminated 4 districts of Bryansk region. The tendency of dose dependence of thyroid cancer incidence was found.

IODINE-131 CONTAMINATION

In total about 1,800 PBq of I-131 was deposited in the environment as a result of the Chernobyl accident [1]. The most contaminated territories in Russia are located in Bryansk, Tula, Orel and Kaluga regions [2] (see Table 1).

Data on the radionuclide composition of fallout and atmospheric aerosol samples have been obtained by the Institute of Experimental Meteorology (SPA “TYPHOON” now, Obninsk, Russia) [2]. The first soil samples near the Chernobyl NPP were collected on 30.04.86. The fallout and atmospheric aerosol samples have been taken beginning on 27.04.86. The principal measurements of the isotopic composition of environmental samples have been performed after 10.05.86. The basic body of soil samples, for which

Table 1. Population residing in the contaminated regions following the Chernobyl accident (Russia, 1991.01.01).

N	Regions	Cs-137 soil contamination: 37-185 kBq/m^2 (1-5 Ci/km^2)		Cs-137 soil contamination: 185-555 kBq/m^2 (5-15 Ci/km^2)		Cs-137 soil contamination: >555 kBq/m^2 (>15 Ci/km^2)		Subtotal	
		No of settlem.	Popu-lation	No of settlem.	Popu-lation	No of settlem.	Popu-lation	No of settlem	Popu-lation
1	Belgorod	56	1940					56	1940
2	Bryansk	829	227220	288	147361	275	93100	1392	467681
3	Voronezh	35	11940					35	11940
4	Kaluga	289	78078	135	15492			424	93570
5	Kursk	230	134189					230	134189
6	Orel	1987	326581	64	17648			2051	344229
7	St.-Petersburg	44	19591					44	19591
8	Lipetsk	149	38882					149	38882
9	Ryasan	646	182000					646	182000
10	Tambov	22	3569					22	3569
11	Tula	1736	768773	311	166776			2047	935549
12	Ul'yanovsk		9000						9000
13	Penza		51000						51000
14	Smolensk		10000						10000
15	Mordoviya		20000						20000
Total			1882763	798	347277	275	93100	7096	2323140

the isotopic composition is known, was collected and measured in the second half of 1986 and during 1987, i.e. when iodine-131 activity was already negligible. As a result, direct measurements of environmental iodine-131 are very scarce now.

To get detailed information on soil and atmospheric contamination by I-131 in the first period after the Chernobyl accident, all available data were used on the isotopic composition of soil (43 points), fallout (14 points) and atmospheric aerosol samples (7 points) [3]. To verify the validity of estimating the isotopic composition of soil, fallout and aerosol samples, the $^{134}Cs/^{137}Cs$ activity ratios were determined simultaneously with $^{131}I/^{137}Cs$ activity ratios. The accuracy of the ratios for soil samples was estimated as 15-25%, for the fallout - as 20-30% and for aerosol - 30-50%. The $^{134}Cs/^{137}Cs$ ratio averaged for the reactor core during the Chernobyl accident is known to be 0.53 with a high accuracy of SD=0.02.

From the very beginning when plotting the fields of soil I-131 contamination, it was attempted to connect this contamination with the density of soil contamination by Cs-137 (having a relatively long half-life, $T_{1/2}$ = 30.2 years) for which the measurement data are maximum available. However, such a description may be accepted only for rough estimates of I-131 activity. In fact, there were notable differences in the radionuclide composition of contamination due to the peculiarities of transfer of radioactivity and to the variations of transfer directions in the atmosphere: the I-131 to Cs-137 activity ratios did not exceed a value of 15 in Russia (from 4.4 to 15, at 1st of May 1986), whereas in some territories of Belarussia these ratios were remarkable greater – from 5 to 42 on 1 of May 1986 [1,2]. Therefore, even if Cs-137 contamination levels were equal, the values of iodine radioisotopes intake could be different for various regions.

To reconstruct the trajectories of radionuclide transfer in the first period after the accident, the data were collected on wind velocity and direction at various heights above the sea level for the European territory of the former USSR (ETU) and also precipitation data were collected between 23^0-38^0 E and 46^0-56^0 N from the end of April to late May 1986 [3].

Using the trajectories analyses, the time of particle arrival to a given site, district or region for each height level was estimated [2]: the earliest time of arrival and the latest time of leaving of air particles were determined for a given site or region (Tables 2-4) This time was considered as a probable period during which a given territory was radioactively contaminated.

Table 2. Data on air particles transfer trajectories in Bryansk region (Russia).

N	Settlements	Trajectory departure from Chernobyl - 27 - 29 April 1986						
		1	2	3	4	5	6	7
1	Bryansk	- -	- -	-	-	17/28 19/28	06/27	22.7
2	Dubrovka	- -	- -	-	-	21/28 00/29	03/27	no *
3	Dyatkovo	- -	- -	-	-	00/29 03/29	06/27	no *
4	Zhukovka	- -	- -	-	-	20/28 21/28	06/27	no
5	Kletnya	- -	- -	-	-	18/28 19/28	06/27	-
6	Zhiryatino	- -	- -	-	-	17/28 19/28	07/27	-
7	Karachev	- -	- -	-	-	17/28 19/28	09/27	1.3
8	Trubchevsk	- -	- -	-	-	23/29 01/30	03/27	4.0
9	Navlya	- -	- -	-	-	14/28 16/28	09/27	no
10	Pochep	- -	- -	-	-	20/29 22/29 12/28 14/28	03/27 09/27	no 5.7
11	Fokino	- -	- -	-	-	19/28 21/28	07/27	22.7
12	Komarichi	14/28 0.2 04/29 0.7	16/29 0.7 06/29 0.7	08/27 08/28	- -	14/28 15/28 - -	08/27	- -
13	Suzemka	11/29 0.7 05/29 0.7 - -	13/29 0.7 07/29 0.7 - -	03/29 21/28 -	- - -	- - - - 10/29 11/29	- - 00/29	- - -
14	Klintsy	- -	- -	-	-	12/28 13/28	09/27	no *
15	Starodub	- -	- -	-	-	11/28 13/28	09/27	no
16	Krasnaya Gora	- -	- -	-	-	14/28 15/28	07/27	no
17	Mglin	- -	- -	-	-	17/29 21/29	03/27	no *
18	Sevsk	12/29 0.7 04/29 0.7 11/29 0.7	13/29 0.7 05/29 0.7 16/29 0.2	10/27 18/28 03/29	no no 0.5	- - - - 12/29 16/29	- - 00/29	- - 0.5
19	Lokot	- -	- -	-	-	14/28 15/28	11/27	-
20	Surazh	- -	- -	-	-	16/29 20/29	03/27	no
21	Unecha	- - - -	- - - -	- -	- -	14/28 15/28 18/28 21/29	08/27 03/28	no no
22	Vigonichi	- -	- -	-	-	16/28 17/28	08/27	-

Explanation for columns 1-7:
1 - earliest date of the trajectory arrival, hour/day (hh/dd) and trajectory height above the sea level, km;
2 - latest date of the trajectory departure, hour/day (hh/dd) and trajectory height above the sea level, km;
3 - date of the air particles trajectory departure from the Chernobyl reactor, hour/day (hh/dd);
4 - precipitation, mm/day (no - no precipitation, * - data related to the nearest settlement);
5 - earliest date of the trajectory arrival at the height 0.45 km above the sea level, hour/day (hh/dd) and latest date of this trajectory departure, hour/day (hh/dd);
6 - date of the 0.45 km air particles trajectory departure from the Chernobyl reactor, hour/day (hh/dd);
7 - precipitation, mm/day (no - no precipitation, * - data related to the nearest settlement);

Table 3. Data on air particles transfer trajectories in Tula region (Russia).

N	Settlements	Trajectory departure from Chernobyl - 27 - 28 April 1986						
		1	2	3	4	5	6	7
1	Efremov	- -	- -	-	-	01/29 02/29	19/27	no
2	Novomoskovsk	- -	- -	-	-	06/29 09/29	08/27	1.7 *
3	Uzlovaya	- -	- -	-	-	03/29 05/29	09/27	1.7
4	Bogoroditsk	- -	- -	-	-	02/29 04/29	10/27	no
5	Klimovsk	- -	- -	-	-	05/29 07/29	06/27	1.7 *
6	Kurkino Kurkino	02/29 0.2 17/29 0.2	11/29 0.7 17/29 0.2	18/27 18/28	no * no *	02/29 04/29 - -	18/27 -	no * -
7	Epifan Epifan	05/29 0.2 08/29 0.7	10/29 0.7 10/29 0.7	12/27 00/28	- -	- -	-	-
8	Volovo Volovo	01/29 0.2 08/29 0.2	09/29 0.7 09/29 0.7	15/27 15/28	no no	01/29 02/29 - -	15/27 -	no -
9	Chern	- -	- -	-	-	22/28 23/28	12/27	1.6
10	Plavsk	- -	- -	-	-	01/29 03/29	09/27	0.3
11	Schekino	- -	- -	-	-	07/29 08/29	06/27	no *
12	Kireevsk	- -	- -	-	-	03/29 06/29	09/27	no *
13	Arkhangelskoye Arkhangelskoye	23/28 0.2 13/29 0.7	14/29 0.7 14/29 0.7	18/27 18/29	- -	23/28 01/29 - -	18/27 -	- -

Explanations for columns 1-7 are shown in Table 2.

Table 4. Data on air particles transfer trajectories in Kaluga region (Russia).

N	Settlements	Trajectory departure from Chernobyl - 27- 28 April 1986						
		1	2	3	4	5	6	7
1	Lyudinovo	- -	- -	-	-	02/29 04/29	06/27	no*
2	Zhizdra	- -	- -	-	-	23/28 01/29	06/27	no
3	Duminichi	- -	- -	-	-	23/28 01/29	06/27	no*
4	Khvastovichi	- -	- -	-	-	20/28 22/28	06/27	0.7*
5	Ul'yanovo	- -	- -	-	-	03/29 06/29	06/27	no*

Explanations for columns 1-7 are shown in Table 2.

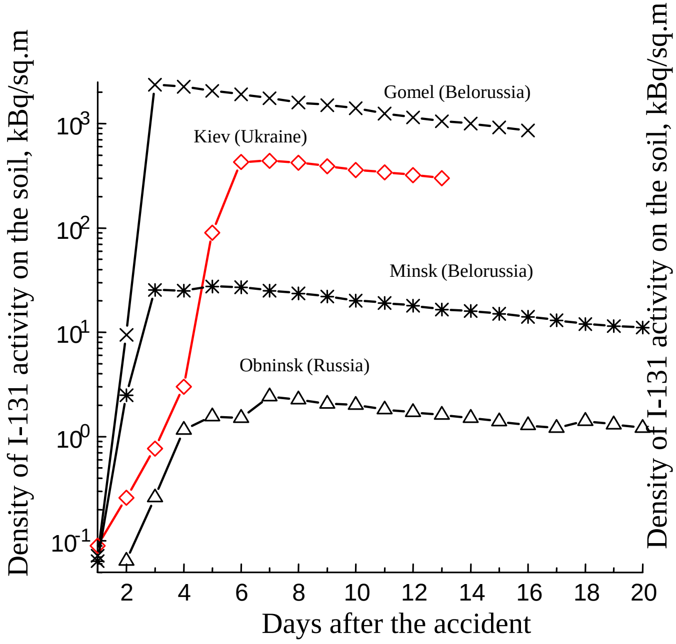

Fig. 1. Accumulation of I-131 activity in soil.

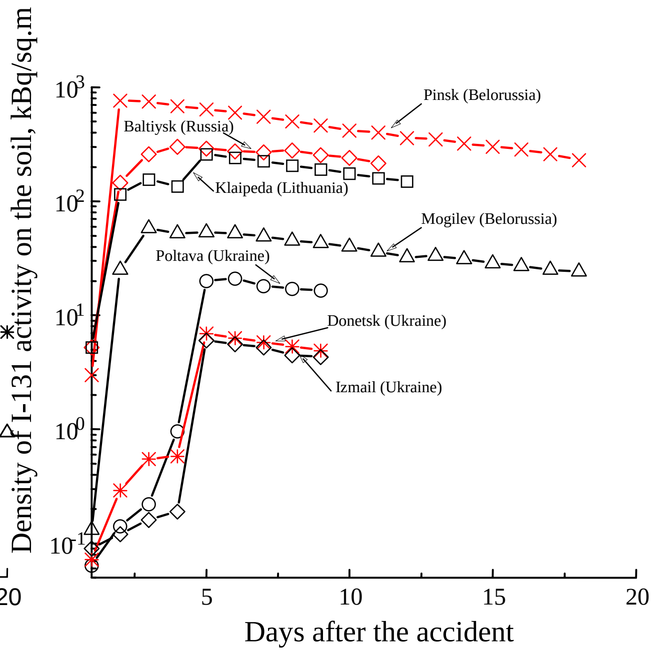

Fig. 2. Accumulation of I-131 activity in soil.

As noted above, the data on the results of direct measurements of radioactive iodine isotopes in the environment after the Chernobyl accident are scarce: for example the time dependences of I-131 fallout are known only for a few location over all territory of FSU [2-5]. The time integration of such kind of dependencies show that a major part (more than 80-90 %) of I-131 contamination was accumulated in studied territories by the moment D + 5 days (Fig.1,2). These data are confirmed by analyzing the dose rate dependence on time at some settlements. For example, in Novozybkov (Bryansk region, Russia) as well as in Chernobyl (Ukraine), Pinsk (Belorussia) and Semenovka (Ukraine), the dose rate trend on time shows that a dose rate had increased only during the radioactive cloud passage, i.e. prior to D+5[2,4]. After the cloud passage the dose rate had rapidly decreased.

Despite the shortage of the available data with the results of I-131 measurements, this information is very valuable because the knowledge of I-131/Cs-137 ratios and time parameters of fallout are very important for thyroid dose estimations.

THYROID DOSES

Intake of radioactive iodine isotopes, mainly I-131 in milk, was the main source of thyroid irradiation of population in contaminated settlements. The results of direct measurements of radioactive iodine content in human thyroid gland in Byelorussia together with available data on I-131 and Cs-137 contamination of the soil were used for development of semi-empirical model for reconstruction of thyroid absorbed doses in cases when the measurements were not performed in 1986 [2]. For validation and tuning of this model in Russian territories about 30,000 direct measurements of radioactive iodine content in human thyroid gland in Kaluga and Bryansk regions (Russia) [6] and all available data on I-131 and Cs-137 contamination of the soil [4,5] were used.

Dose estimation by semi-empirical model

Mean dose values in exposed population of each contaminated settlement over Russia where the density of Cs-137 soil contamination exceeded 3.7 kBq/m^2 (0.1 Ci/km^2) were evaluated using the model. Collective doses for contaminated “spots” in 4 most contaminated Russian regions were estimated as the following [2]: 72,600 person-Gy for Bryansk region (in population of 1,137,100 persons), 16,900 person-Gy for Orel region (in population of 448,000 persons), 13,400 person-Gy for Tula region (in population of 1,310,000 persons) and 3,400 person-Gy in Kaluga region (in population of 213,500 persons) (see Table 5 and Table 6).

Dose estimation based on direct measurement data

According to the estimations (Table 7), which are based on the results of direct measurements of I-131 activity in thyroid gland in the inhabitants of the contaminated district in Kaluga and Bryansk regions [6], the median of individual thyroid dose values in Kaluga region (7 districts) varies from 30 mGy for children to 8 mGy for adults (geometric standard deviation of about 2.6). As seen in Table 8, in Bryansk region (5 districts) the median dose values for adults are in the range from 140 mGy to 30 mGy (geometric standard deviation of about 2.7).

THYROID CANCER

Annual thyroid cancer morbidity over 1986-2000 years in residents of the most affected Bryansk region, aged 0-50 years at the moment of the accident, is presented in Table 9-11.

All thyroid cancer cases (in total 1201 cases) in patients aged 0–50 years at the period of iodine radionuclides action (May-June 1986), which were registered in the Bryansk Regional oncological registry, were taken as the basic material for analysis. Age limit in 50 years is explained mainly by low life span of Russian population (around 70 years for females and 60 for males). We believe, that the used age period (0–50 years at the moment of the accident and correspondingly 0–65 years at the moment of diagnosis) is large enough for elucidation of the general features of the post-Chernobyl thyroid cancer situation. Annual thyroid cancer morbidity was followed up in this cohort of population since 1986 to 2000 and summarized over 5-year periods (1986-1990, 1991-1995, 1996-2000) in different age groups (0-4 years, 5-0, 10-14, etc.). Such division permitted to form comparable subgroups for both sex ans age over all period of surveillance.

Average number of Bryansk region population in the age cohort 0-50 years at the moment of the accident (and correspondingly in the next 5-year periods) comprised approximately 1 million and in each age group around 100,000 (Table 9). Only in the age group 40-44 year (period 1986-1990), which corresponds to 45-49 year (period 1991-1995) and 50-54 year (period 1996-2000), there is a demographic fall as a consequence of the World War II. It should be noted that the number of the total examined cohort as well as the numbers of population in individual subgroups did not markedly change during the analyzing period. This permitted to carry out a correct analysis of thyroid cancer morbidity in age groups.

Table 10 demonstrates annual distribution of thyroid cancer cases in patients aged 0-50 at the moment of the accident (Bryansk cohort, 0-64 years old at diagnosis, both sexes). Table 11 presents thyroid cancer incidence rate in the same cohort averaged over five years periods after the accident.

Table 10 and Table 11 demonstrate that during the first five years after the accident (1986-1990) annual thyroid cancer morbidity in different age groups (0-4 years, 5-9, 10-14, etc.) remained at quite stable levels. Since 1991 a stable increase of the number of thyroid cancers in all age groups of the studied population has started. It’s seems to be that the minimal duration of the latent period of radiogenic thyroid

Table 5. Thyroid doses : Bryansk and Tula regions, Russia.

Cs-137 soil contaminat. density, kBq/m^2	Population, (×10^3 pers.)	Average Cs-137 soil contaminat. density, kBq/m^2	Average thyroid dose in population, mGy *	Collective dose in population, (×10^3 person-Gy) *
BRYANSK				
3.7- 37	670	12.6	9.5	6.39
37 - 185	227	86.6	58.9	13.4
185 - 555	147	336	176	25.9
>555	93.1	918	289	26.9
Total	1137.1		64	72.6
TULA				
3.7- 37	370	24.4	4.43	1.64
37 - 185	770	112	11.2	8.64
185 - 555	170	281	18.3	3.11
Total	1310		10.2	13.39

* - Taking into account the real beginning of the pasture period.

Table 6. Thyroid doses: Kaluga and Orel regions, Russia.

Cs-137 soil contaminat. density, kBq/m^2	Population, (×10^3 pers.)	Average Cs-137 soil contaminat. density, kBq/m^2	Average thyroid dose in population, mGy *)	Collective dose in population, (×10^3 person-Gy) *
KALUGA				
3.7- 37	120	20.3	9.50	1.14
37 - 185	78	98.4	21.9	1.71
185 - 555	15.5	263	35.5	0.55
Total	213.5		15.9	3.40
OREL				
3.7- 37	100	23.3	17.3	1.73
37 - 185	330	90.3	42.0	13.85
185 - 555	18	220	72.7	1.31
Total	448		37.7	16.9

* - Taking into account the real beginning of the pasture period.

Table 7. Estimated parameters of individual thyroid dose distribution (7 investigated districts of Kaluga region).

Items[a]	Groups by age at the time of the accident[b]					
	-1	1-2	2-7	7-12	12-17	17-
N	1075	989	7491	6440	4997	5732
MID(mGy)	550	530	460	320	250	250
DA (mGy)	52	43	23	15	14	13
SD (mGy)	58	52	29	17	17	15
DM (mGy)	31	26	14	10	8.3	8.1
GSD	2.7	2.7	2.6	2.4	2.7	2.7

[a]: N=number of persons with the results of direct measurements in given age range; MID=maximum individual dose; DA=arithmetic mean dose; SD=standard deviation; DM=median dose; GSD=geometric standard deviation.
[b]:Include the left end while exclude the right end.

Table 8. Estimated parameters of individual thyroid dose distribution (five investigated districts of Bryansk region).

District	Arithmetic mean dose (mGy)	Median dose (mGy)[a]	Number of adults
Gordeevskiy	120	74	75
Klimovskiy	48	31	9
Klintsovskiy	62	41	10
Krasnogorskiy	223	143	93
Novozybkovskiy	46	30	83

[a]Geometric standard deviation is 2.7.

Table 9. Average size of cohort and number of persons in different age groups in 5-year periods.

(Bryansk cohort, 0-50 years old at the moment of the accident, both sexes)

Years	Number of population in different age groups (persons)												
	Total number of population in cohort	0 – 4	5 – 9	10 – 14	15 – 19	20 – 24	25 – 29	30 – 34	35 – 39	40 – 44	45 – 49	50-54	55-59
1986-1990	988315.4	110431.8	103914.4	100992.8	95863.8	94283.0	114403.4	115018.0	102798.2	64859.2	85750.8	+	+
1991-1995	974626.8	-	111004.4	104406.8	98640.4	88211.2	95248.8	116310.2	113623.8	100113.4	59952.8	87115.0	+
1996-2000	982553.7	-	-	114588.0	104153.3	96770.0	89934.3	102560.0	121572.0	111663.7	96125.0	51610.3	93577.0

Notes: 1. Sign (-) means the shift-out of cohort after 5-year periods.
2. Sign (+) means that age groups 0-49 analyzed in period 1986-1990 entered in the age groups 5-54 in period 1991-1995 and the age groups 10-59 in period 1996-2000.

Table 11. Thyroid cancer incidence rate at diagnosis in persons aged 0–50 years at the moment of the Chernobyl accident avareged over 5 years periods after the accident. (Bryansk cohort, both sexes, per 100 000 of population**)**

Year of diagnosis	Number of thyroid cancer cases in different age groups												
	0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64
1986-1990	0	0	1.9	2.1	6.4	15.7	26.1	35.0	37.0	29.2	27.3	+	+
1991-1995	-	6.5	14.6	17.5	21.9	27.7	35.4	58.2	70.3	74.1	57.2	49.7	+
1996-2000	-	-	19.2	30.6	28.1	35.6	37.5	70.6	87.8	133.3	116.8	74.7	63.0

Notes:
Sign (-) means the absence of patients in the corresponding age groups owing to their natural shift in elder age groups.
Sign (+) means the absence of patients in the corresponding age groups owing to restriction of the analyzing cohort by the of age 50 years old at the moment of the accident.

Table 10. Annual distribution of thyroid cancer cases in patients aged 0-50 at the moment of accident.
(Bryansk cohort, 0-64 years old at the moment of diagnosis, both sexes)

Year of diagnosis	**Number of thyroid cancer cases in different age groups**															
	0-4	5-9	10-14	15-19	20-24	**Sub total 0-24**	25-29	30-34	35-39	40-44	45-49	**Sub total 25-49**	50-54	55-59	60-64	**Total 0-64**
1986	0	0	0	0	1	**1**	4	5	4	1	2	**16**	4	+	+	**21**
1987	0	0	1	1	1	**3**	4	5	6	5	7	**27**	2	+	+	**32**
1988	0	0	0	0	1	**1**	5	5	10	5	4	**29**	7	+	+	**37**
1989	0	0	0	0	3	**3**	3	10	7	6	6	**32**	6	+	+	**41**
1990	0	0	1	1	0	**2**	2	5	9	7	6	**29**	7	+	+	**38**
Sub total 1986-1990	**0**	**0**	**2**	**2**	**6**	**10**	**18**	**30**	**36**	**24**	**25**	**133**	**26**	+	+	**169**
1991	-	1	0	2	1	**4**	8	6	8	7	5	**34**	13	+	+	**51**
1992	-	3	0	0	4	**7**	3	8	7	16	6	**40**	12	3	+	**62**
1993	-	1	0	5	3	**9**	6	10	15	11	11	**53**	8	13	+	**83**
1994	-	2	7	7	5	**21**	4	7	18	7	16	**52**	12	10	+	**95**
1995	-	-	8	3	7	**18**	8	10	15	17	16	**66**	6	14	+	**104**
Sub total 1991-1995	-	**7**	**15**	**17**	**20**	**59**	**29**	**41**	**63**	**58**	**54**	**245**	**51**	**40**	+	**395**
1996	-	-	3	3	2	**8**	5	5	6	14	14	**44**	7	16	3	**78**
1997	-	-	7	3	6	**16**	5	8	17	15	18	**63**	8	10	12	**109**
1998	-	-	7	5	2	**14**	4	4	17	13	17	**55**	9	11	8	**97**
1999	-	-	2	10	8	**20**	9	13	14	22	29	**87**	28	20	15	**170**
2000	-	-	2	10	8	**20**	10	11	29	29	26	**105**	29	8	21	**183**
Sub total 1996-2000	-	-	**21**	**31**	**26**	**78**	**33**	**41**	**83**	**93**	**104**	**354**	**81**	**65**	**59**	**637**
Total 1986-2000	**0**	**7**	**38**	**50**	**52**	**147**	**80**	**112**	**182**	**175**	**183**	**732**	**158**	**105**	**59**	**1201**

Notes:
1. In shaded lines and columns the summarized data over time intervals and age groups are presented.
2. Sign (-) means the absence of patients in the corresponding age groups owing to their natural shift in elder age groups.
3. Sign (+) means the absence of patients in the corresponding age groups owing to restriction of the analyzing cohort under 50 years old at the moment of the accident.

cancer is equal abut 5 years. After that we can see the rise of thyroid cancer morbidity in all age groups due to possible influence of the Chernobyl accident.

One of the key questions regarding the radiogenic nature of thyroid cancer following the Chernobyl accident was focused on its dose dependence of the thyroid cancer incidence. There was an attempt to investigate this question using the available individual data for 26 thyroid cancer cases in Bryansk region.

The retrospective individual dose estimations were performed for 26 thyroid cancer cases (17 female and 9 male cases in the age 0-18 years old at the moment of accident) [7] which had been registered before the end of 1997 in Novozybkovsky, Krasnogorsky, Klintsovsky and Klimovsky districts – the four of the most contaminated territories of Bryansk region. The verification of diagnosis in 18 cases was performed by a group of experts at an international level: Prof. D. Williams (Cambridge, UK), Prof. E. Lushnikov (Obninsk, Russia), Prof. G. Frank (Moscow), Dr A. Abrosimov (Obninsk). Other cases were diagnosed and operated in Children Oncology Research Institute of Oncological Scientific Centre (Moscow).

A special questionnaire was used to gather data for individual thyroid dose reconstruction, including information about milk consumption, leafy vegetable consumption, and use of thyroid blocking agents. Individual doses were retrospectively estimated using semi- empirical model [2]. In Table 12 the reconstructed individual thyroid doses are presented for different dose ranges: < 0.25 Gy, 0.25 Gy ≤ 0.5 Gy, 0.5 Gy ≤ 0.75 Gy, 0.75 Gy ≤ 1.0 Gy and ≥ 1.0 Gy.

The results of analysis of available individual dose estimates based on thyroid counting to determine I-131 content in May-June 1986 were applied in order to estimate the numbers of young population related to various individual dose ranges [6]. Then, the numbers of thyroid cancer cases corresponding to the different individual dose ranges were referred to the young population of the same dose ranges (Table 12).

The “background” level of thyroid cancers for the investigated population during 11.7 years after the accident was taken into account. For calculation of the background level the statistical data of [8] were used. The results of dose dependence estimation are presented in Table 12 and in Figure 3.

CONCLUSIONS

- The most contaminated territories in Russia following the Chernobyl accident are located in Bryansk, Tula, Orel and Kaluga regions. According to the trajectory analysis of the radioactive plumes from Chernobyl, the main part (more than 80-90 %) of I-131 contamination in these regions was formed by the five days after the accident. There were notable differences in the radionuclide composition of contamination due to the peculiarities of transfer of radioactivity and to the variations transfer directions in atmosphere: the I-131 to Cs-137 activity ratios did not exceed value of 15 in Russia, whereas in the some territories of Byelorussia these ratios were remarkable greater than 15.

Table 12. Estimation of thyroid cancer incidence dose dependence for population in four contaminated districts of Bryansk region (age group < 18 years old at the moment of accident); see Figure 3 as well.

Range of individual thyroid doses, Gy	Population in the dose range, persons	Number of thyroid cancer cases in the dose range	“Background” level of thyroid cancers for the population in the dose range	Thyroid dose in cancer cases, Gy,(D)	Standard deviation of thyroid dose in cancer cases, Gy	Incidence of thyroid cancer cases in the dose range per 10^4 persons
<0.25	29316	8	1.53	0.073	0.069	2.21
0.25≤0.5	14439	5	0.752	0.32	0.096	2.94
0.5≤0.75	9294	6	0.484	0.67	0.043	5.93
0.75≤1.0	2654	3	0.138	0.87	0.095	10.1
≥1.0	2960	4	0.154	1.25	0.27	13.0

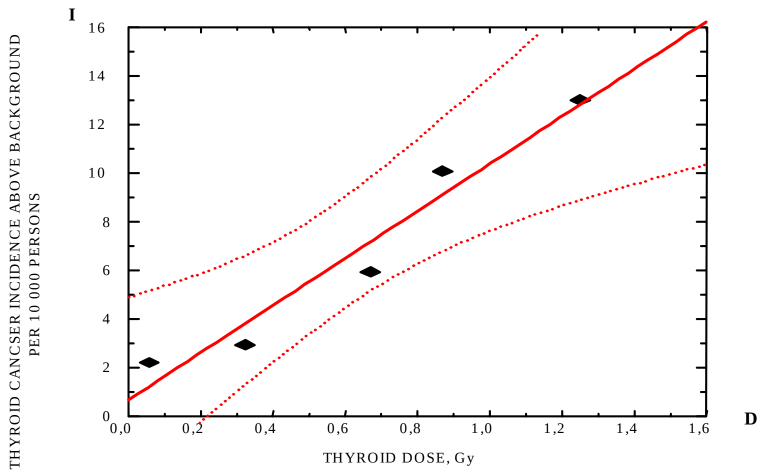

Fig. 3.. THYROID CANCER INCIDENCE VS INDIVIDUAL THYROID DOSES
four districts of Bryansk region: 26 cases from 04.1986 till 12.1997).
Only persons of 18 years old by 04 - 05.1986.
Upper and lower curves are 95% confidence bands.
See Table 3 and relationship (1), (2) as well.

- The results of direct measurements of radioactive iodine content in human thyroid gland in Byelorussia as well as the available data on iodine-131 and Cs-137 contamination of the soil were used for development of semi-empirical model to reconstruct thyroid absorbed doses. For validation and tuning of this model in Russian territories about 30,000 direct measurements of radioactive iodine content in human thyroid gland in Kaluga and Bryansk regions (Russia) and all available data on I-131 and Cs-137 contamination of the soil were used.

- By using semi-empirical model mean thyroid dose values in exposed population of each contaminated settlement over Russia where the density of Cs-137 soil contamination exceeded 3.7 kBq/m^2 (0.1 Ci/km^2) were evaluated. Collective doses for contaminated "spots" in the most contaminated 4 regions were estimated as the following: 72,600 person-Gy for Bryansk region (in population of 1,137,100 persons), 16,900 person-Gy for Orel region (in population of 448,000 persons), 13,400 person-Gy for Tula region (in population of 1,310,000 persons) and 3,400 person-Gy in Kaluga region (in population of 213,500 persons).

- According to the estimations, which are based on the results of direct measurements of I-131 activity in thyroid (Kaluga and Bryansk regions), the median of individual thyroid dose values in Kaluga region (7 districts) varies from 30 mGy for children to 8 mGy for adults (geometric standard deviation of about 2.6). In Bryansk region (5 districts) the median dose values for adults are in the range from 140 mGy to 30 mGy (geometric standard deviation of about 2.7).

- The data on annual thyroid cancer morbidity over 1986-2000 years in residents of the most affected Bryansk region is presented in different age groups. During the first five years after the accident (1986-1990) annual thyroid cancer morbidity remained at quite stable levels. Since 1991 a stable increase of the number of thyroid cancers in all age groups of the studied population has started as a possible result of radiogenic influence of the accidental release of I-131 from the Chernobyl NPP.

- The semi-empirical model was applied to reconstruct individual thyroid doses for 26 thyroid cancer cases (0 - 18 years old at the moment of accident) in the most contaminated 4 districts of Bryansk region. A special questionnaire was used to gather data for individual thyroid dose reconstruction, including information about milk consumption, leafy vegetable consumption, and use of thyroid blocking agents. The incidence rate of thyroid cancer cases corresponding to the different individual dose ranges were calculated by referring the number of thyroid cancer case to the young population of the same dose ranges. The tendency of dose dependence of thyroid cancer incidence was found.

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References.

1. UNSCEAR 2000 Report to the General Assembly. Annex J: Exposured and Effects of the Chernobyl Accident. In: International Journal of Radiation Medicine. Special Issue. Vol. 2-4 (6-8). 2000. Kiev. P. 3-109.
2. Stepanenko V.F., Tsyb A.F., Parshkov E.M. et al. Retrospective thyroid absorbed doses estimation in Russia following the Chernobyl accident: progress and application to dosimetrical ecaluation of childhood thyroid cancer morbidity. In: “Effects of low-level radiation for residents near Semipalatinsk nuclear test site”. Proc. of the Second Hiroshima International Symposium, Hiroshima, July 23-25, 1996 (Edited by M. Hoshi, J. Takada, R. Kim, Y. Nitta). Hiroshima University, 1996, p. 31-84.
3. Environmental Radioactive contamination after Chernobyl NPP Accident. IEM SPA “Typhoon”. Obninsk. p.305, 1986 (in Russian).
4. Orlov M.Yu., Snykov V.P., Khvalensky Yu.A. et. al. Radioactive contamination of Belorussia and Russia territories after the Chernobyl accident. Atomnaya Energiya. 72:4. p. 371-376, 1992 (in Russian).
5. Makhonko K.P., Kozlova E.G., Volokitin A.A. Radioiodine accumulation on soil and reconstruction of doses from iodine exposure on the territory contaminated after the Chernobyl accident. In: Radiation and risk, Bulletin of the National Radiation and Epidemiological Registry. English translation of Russian issue N7. Cambridge, MA; 1997. p. 90-142.
6. Stepanenko V.F., Gavrilin Yu.I., Khrouch V.T. et al. Re-evaluation of thyroid doses in Russia after the Chernobyl Accident. In: International Congress Series. Elsevier Science. 642 ,2001 (in press).
7. Stepanenko V., Tsyb A., Skvortsov V. et al. New results of thyroid retrospective dosimetry in Russia following the Chernobyl accident. In: “Radiation and thyroid cancer”. (Eds.: G. Thomas, A. Karaoglou, E.D. Williams). World Scientific Publishing Co.Pte. Ltd. Singapore-New Jersey-London-Hong-Kong. 1999, p. 333-338.
8. Dvorin VV, Axel EA, Trapesnikov NN. The statistics of malignant neoplasams in Russia and CIS. Moscow, 1995 (in Russian).