Reconstruction of the Individual Cumulative Doses of Radiation Exposure in Cases of Infant Leukemia Registered within the Early Period after Chernobyl Accident

SKRJABIN Anatoly[1], SAVVA Natallia[2,3], BELSKY Yury[3], , MATARAS Anastasia[1], HOSHI Masaharu[4]

[1]*Republican Research Center for Radiation Medicine and Human Ecology, Gomel, Belarus*
irg_rnpc@mail.ru
[2]*Belarusian State Medical University, Minsk, Belarus n_savva@yahoo.com*
[3]*Belarusian Research Center for Pediatric Oncology and Hematology, Minsk, Belarus*
[4]*Research Institute for Radiation Biology and Medicine, Hiroshima University*

Abstract

Individual cumulative doses in all cases of infant leukemia developed after Chernobyl accident within the years 1986 and 1987 in residents of Belarus have been reconstructed. Totally, 20 children were included into this population-based study. The median cumulative dose was 0.21mSv.

Introduction

Infant leukemia in children exposed *in utero* due to Chernobyl accident has been assessed as possible effect of radiation [1, 2]. Some attempt were made within a few ecological and one case-control study to establish the dose relationship in children on the contaminated areas in Belarus, Russia, Ukraine, Germany, Greece, Romania, etc., however, without any significant results [3-7]. However, reconstruction of individual doses has been never performed.

Aim of this study was a reconstruction of cumulative doses in all Belarusian children with infant leukemia which were born in 1986-1987 and were affected during the Chernobyl accident in utero and/or within first year of life. Tasks of the study were as following: to reconstruct individual cumulative doses; to assess cumulative doses absorbed of embryo and fetus exposing in utero; to assess the time-related role of dose forming factors; to calculate the coefficient of child/mother dose; to compare the calculated doses with possible leukemogeneic threshold.

Patients and Methods

All children with infant leukemia, residents of Belarus, which were in utero and/or were at their first year of life at Chernobyl accident supposed to be eligible for this population-based study. Totally, 20 cases which were born from August 22, 1986 to December 25, 1987 (during 4–20 months of early post-Chernobyl period) have been included for the dose reconstruction.

Leukemia was established as infant if age of a child was less than 1 year. Data for every case of infant leukemia were provided by population-based Childhood Cancer Sub Registry of Belarus run at Belarusian Research Center for Pediatric Oncology and Hematology (Minsk, Belarus).

Data for doses assessment included subject's date and place (toponim) of birth, radiological characteristics of toponim (Table 1). As shown in the Table 1, cases with infant leukemia were registered in 5 of 6 oblasts excepting Grodno oblast. 13 toponims (2/3) were located in oblasts of Gomel and Mogilev. Toponims were revealed in almost all radiological zones (9 of 10) excepting Zone 1 (South part of Gomel oblast) that has been mostly contaminated after Chernobyl accident. Density of σ_{137Cs} toponim's area contamination was very low with median ~15 kBq/m^2 or about 0.40 Ci/km^2 (~93 kBq/m^2 as maximum).

Table 1. Subject's address and radiologic characteristics of toponim.

Subjects[a]	Date of Birth	Address [b] (Toponim[c])	Radiological Characteristics of Toponim	
			σ_{137Cs}, kBq/m^2 [d]	Zone Index[e]
1	22.08.1986	grp. Bereza (Brest obl.) [f]	6.512	9
2	17.11.1986	d. Mayskoye, Zhlobin region, (Gomel obl)	93.28	5
3	06.12.1986	pgt Rossony (Vitebsk obl)	2.59	10
4	30.12.1986	gop. Krichev (Mogilev obl)	18.17	5
5	01.02.1987	Minsk city	4.181	8
6	04.02.1987	Minsk city	4.181	8
7	16.02.1987	Gomel city	80.77	4
8	02.03.1987	Mogilev city	24.79	6
9	03.03.1987	Minsk city	4.181	8
10	13.03.1987	d. Ostashkovichi, Svetlogorsk region, (Gomel obl)	32.08	5
11	26.03.1987	d. Zaprosie, Luninetsky region (Brest obl)	47.25	7
12	26.04.1987	gop. Kalinkovichi (Gomel obl)	43.81	2
13	01.06.1987	d. Zhgun, Dobrush region (Gomel obl)	30.86	3
14	05.06.1987	d. Kurenec, Vileisky region (Minsk obl)	1.591	9
15	03.07.1987	gop Bobruisk (Mogilev obl	8.029	5
16	06.08.1987	gop Zhlobin (Gomel obl)	49.69	5
17	16.09.1987	d. Dvorec, Luninetsky region (Brest)	68.89	7
18	15.10.1987	d. Porech'e, Octyabrsky region (Gomel obl)	11.8	5
19	22.12.1987	gop. Bobruisk (Mogilev obl)	8.029	5
20	25.12.1987	pgt. Uzda, Uzdensky region (Minsk obl)	1.887	9

Notes:
[a] subjects are placed in chronological order according to the date of birth;
[b] questionnaire data of mother's migration during the pregnancy and after delivery are included;
[c] toponim is an address of a child's birth being the same as a place of mother's living during her pregnancy;
[d] surface fallout density activity by^{137}Cs;
[e] zones of radioactive fallouts;
[f] type of settlement (grp –city of raion level, pgt – village city-type, gop –city of oblast level, d – village)

Duration of antenatal and postnatal periods has been used for cumulative doses calculation of subject (Table 2).

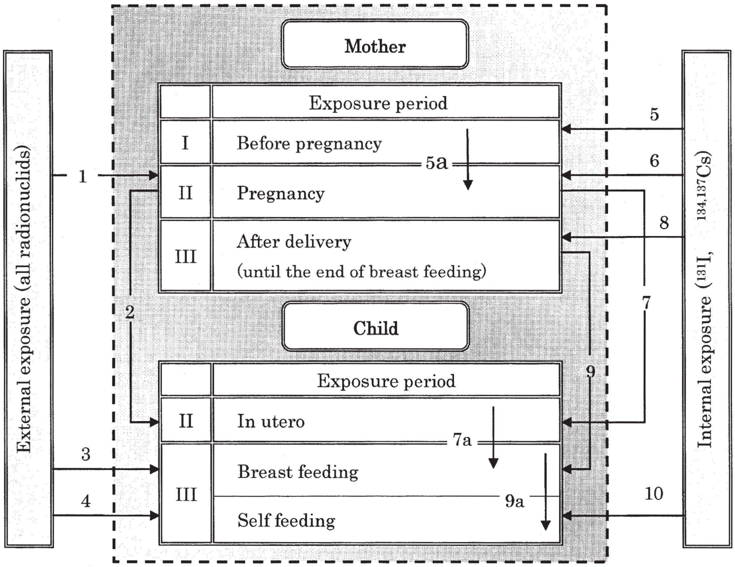
Table 2. Estimated duration of subject's exposure during the antenatal and postnatal phases.

Subjects	Period I, *in utero*, in days	Period II, postnatal [a], in days
1	118	119
2	205	0[b]
3	224	20
4	248	0
5-20	274	Subjects 16 and 17 – 0, Median ~ 95, Max – 342.

Notes: [a] period from the date of birth to date of infant leukemia diagnosis; [b] infant leukemia was diagnosed at birth

Dose Estimation

We assumed that subject's dose depends on the mother's dose exposure (Picture 1).



Picture1. Pathways and sources of dose formation within a system "Mother – Child".

Description.

External exposure:

1. (II) during a pregnancy;
2. (II) an embryo and a fetus (*in utero*);
3. (III) a child during breast feeding;
4. (III) a child after breast feeding.

Internal exposure:

5. (I) a mother before conception;

5a. residual dose of mother after Period I;

6. (II) a mother during pregnancy;
7. (II) an embryo and a fetus *in utero*;

7a residual dose of the newborn child;

8. (III) a mother after delivery (until the end of breast feeding);
9. (III) breast feeding of the newborn child;

9a. residual dose of a newborn child after breast feeding;

10. (III) a newborn child after the end of breast feeding.

Thus, according to the Picture 1, a total cumulative effective dose of subject consists of the following parts:

- an external dose of a child *in utero* and in postnatal period;
- an internal equivalent dose of ^{134,137}Cs *in utero* and effective dose of ^{131}I due to their prolong ingress into mother's body before and after pregnancy;
- a residual effective dose of radionuclides *in utero* until the moment of a child birth: the total period up to disease diagnostics;
- a lactation dose of ^{131}I, ^{134,137}Cs due to intake of breast milk;

- a residual lactation dose of a child after stop of breast feeding;
- a dose of non-breast feeding due to radionuclide intake during the period from the end of breast feeding up to diagnostics of leukemia.

Results and discussion

Cumulative dose

Cumulative doses of subjects according to the periods of exposure are presented in the Table 3.

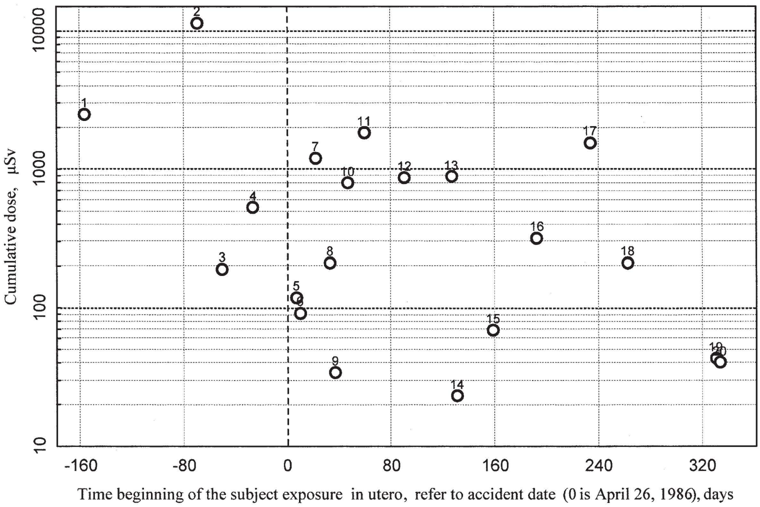
Table 3. Cumulative dose of subject according to the periods of exposure.

Subjects	Exposure **Periods**	
	Period I, *in utero,* μSv	**Period II, postnatal,** μSv
1	2436	45
2	11448	0
3	188	3
4	528	0
5	100	19
6	83	9
7	979	225
8	178	33
9	33	1
10	757	37
11	974	853
12	364	503
13	419	461
14	20	3
15	48	21
16	319	0
17	1562	0
18	145	67
19	38	5
20	16	24

As shown in the Tables 1 and 3, doses correlated with radiological characteristics of toponims. For example, the highest doses were observed in toponims with the highest σ_{137Cs} level and the lowest number of zone index. Median cumulative dose in our study was 210 μSv. Additionally, the dominated role of *in utero* exposure over the total dose has been established in our study: median ratio of subjects doses (I/I+II) was 0.88. As a result, dose in utero was 185 μSv.

Dose forming factors

Two main factors were assessed in the study: a toponim factor (radiological) and a subject's factor related to the time of beginning of exposure *in utero*. It seems that joint effect of both factors caused the very broad variability of cumulative doses (Picture 2). As shown on the Picture 2, the determining factor for the dose forming was a 'toponim factor'. So, the dose in subjects with similar beginning of exposure time (№№ 8, 9 and №№ 13, 14) differed due to various radiological factors. However, almost similar doses were revealed in subjects with analogous radiological factors despite the differences in the beginning of exposure time (№№ 3, 18 and №№ 9, 19, 20).



Picture 2. Time-depending changes of the cumulative dose-distribution.

Trend of dose

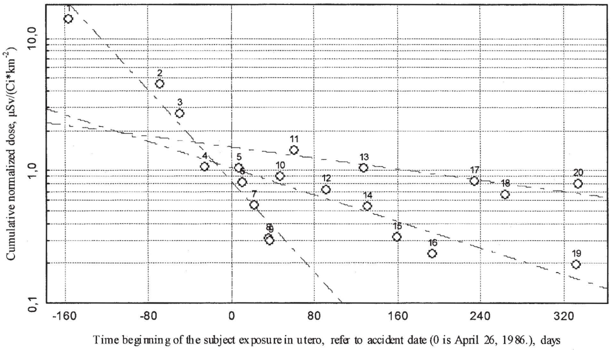
Normalizing of D/σ_{137Cs} performed in this study allowed to observe a relationship between cumulative dose and time more clearly (Picture 3). Three groups of subjects (or toponims) were established by the descent rate of dose (exponential approximation) with $T_{1/2}$ of 35 (iodine dose decrease), 119 and 289 days, relatively. Differs between second and third groups can be explained by unequal ratio of external and internal doses. Analysis of time-depending changes of radionuclides and their exposure pathways (Picture 4) confirmed this assumption. In the beginning, the total dose is formed mostly by radioiodine; however, its impact is dramatically decreased with a relative raise in dose-forming of radiocesium. Since the middle of the summer 1986 the dose has been completely formed by these radionuclides with a little changes during the time and a prevalence of external exposure pathways (median ratio $d_{ext}/d_{(ext+int)} \approx 75\%$).

"Subject/mother" ratio.

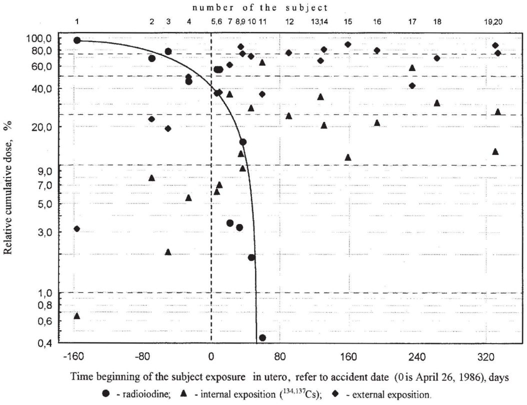
Arithmetic average ratio of cumulative doses subject/mothers (210 μSv and 170 μSv, respectively) was ~0.45. However, the assessment by median ratio revealed that coefficient of a child's defense is 0.75.

Dose comparing to the leukemogeneic threshold.

According to the conservative approaches, the lowest level of leukemogeneic threshold for *in utero* exposure is 20 mSv [7]. The median dose in our study is 0.185 mSv with maximum dose of ~11mSv in only one case. Has the possibility to achieve the leukemogeneic threshold existed after Chernobyl radioactive fallout? Yes, if the radioactive density of 15 kBq/m^2 (0.4 Ci/km^2) forms a dose of 0.21mSv, the border density of area ^{137}Cs contamination will be about 1430 kBq/m^2 (~40 Ci/km^2). As known, a population which lived on such kind of areas in Belarus and received the highest doses was resettled at different times. Therefore, a high probability of additional infant leukemia cases existed.



Picture 3. Time-depending changes of the normalized cumulative dose-distribution.



Picture 4.Time-depending changes of the relative radionuclides doses and their dose-formings pathways.

In general, our retrospective population-based study analyzed data of 20 children with infant leukemia for individual cumulative dose reconstruction for the period included antenatal/postnatal exposure with relation to the radiological characteristics of toponims and date of birth.

By our results, a median cumulative dose in the total group of infant leukemia cases was rather low (0,21 mSv), and 88% of this dose was received in utero. Ratio of the median total doses of a child and his mother was ~0.75.

A decreased trend of a cumulative dose was caused by changes in radiological environment which mostly depended on radioiodine and short-living radionuclides ($T_{1/2}$ 35 days) in the early period after Chernobyl accident and cesium radioisotopes later, from the middle of the summer. At that time, external exposure dominated over internal (0.75/0.25).

Doses reconstructed in our study are too small accounting ~1/100 of the presumable leukemogeneic threshold of irradiation dose *in utero*. That is why we cannot insist that cases of infant leukemia in Belarus are related to the Chernobyl radioactive fallout despite the fact that most of them were registered on the radiologically unfavorable toponims.

Moreover, it is unclear why all the cases were only registered on the territories with low level of contamination and no cases on highly contaminated areas. By the literature, leukemogeneic density of fallout by ^{137}Cs is about ~40 Ci/km^2 (1480 kBq/m^2). In Belarus, 135 000 of inhabitants lived on this area before the evacuation have received middle leukemogeneic doses, and nobody had an infant leukemia in 1986-1987. By our opinion, this fact can be related to high numbers of abortion which were advised within the early years after Chernobyl accident to the woman from highly contaminated areas. However, this matter will required study.

Acknowledgements

This study was performed with the support of International Science and Technical Project B-1910.

References

1. Hall, P. Health consequences after irradiation in utero-human data in effect of in utero exposure to ionizing radiation during the early phases of pregnancy / P. Hall // Proceeding of a seminar in Luxemburg. - 2001. - P. 37-58.
2. Ivanov, E.P. Infant leukemia in Belarus after the Chernobyl accident / E.P. Ivanov, G.V. Tolochko, L.P. Shuvaeva [et al.] // Radiation Environment Biophysics. - 1998. - P. 37.
3. Michaelis, J. Infant leukemia after the Chernobyl accident / J. Michaelis, U. Kaletsch, W. Burkart, [et al.] // Nature. - 1997. - P. 387.
4. Petridou, E. Infant leukemia in utero exposure to radiation from Chernobyl / E. Petridou, D. Trichopoulus, N. Dessypris [et al.] // Nature. - 1996. - P. 382.

5. Davis, S. Childhood leukemia in Belarus, Russia and Ukraine following the Chernobyl power station accident: results from an international collaborative population-based case-control study / Davis S., Day R.W., Kopecky K.J. [et al.] // Int. J. Epidemiol. - 2005.
6. The 2007 Recommendation of the International Commission on Radiological Protection: ICPR Publication 103 // Annals of the ICRP. – 2007.
7. Buldakov L.A., Kalistratova V.S. Radioactivity and Health // Inform-Atom. – Moscow. - 2003 (in Russian: Булдаков, Л.А. Радиоактивное излучение и здоровье / Булдаков Л.А., Калистратова В.С. - М.: Информ-Атом. – 2003).
8. Minenko V.F., Tretjakovich S.S., Trofimik S.V., Kuhta T.S. Reconstruction of medium-group and collective cumulative doses of exposure in residents of settlements of Belarus contaminated during the Chernobyl accident // Methodical Recommendations. – Minsk. – 2003 (in Russian: Миненко, В.Ф. Реконструкция среднегрупповых и коллективных накопленных доз облучения жителей населенных пунктов Беларуси, подвергшихся радиоактивному загрязнению в результате аварии на Чернобыльской АЭС. Методические указания / В.Ф. Миненко, С.С. Третьякевич, С.В. Трофимик, Т.С. Кухта. – 2002).
9. Minenko V.F. Assessment of thyroid absorbed doses in residents of settlements of Belarus // Methodical Recommendation. – Minsk. – 2003 (in Russian: Миненко, В.Ф. Определение поглощенных доз облучения щитовидной железы жителей населенных пунктов Республики Беларусь. Методические указания: утв. 20.03.2003г. / В.Ф. Миненко [и др.]. - Минск. - 2003. - 22 с).
10. Zhuchenko, Y.M. Private communication.
11. ICRP. Doses to the embryo and fetus from intakes of radionuclides by the mother. ICRP Publication 88. - 2001. - *Ann ICRP,* 31 (1-3).
12. ICRP. Doses to infants from ingestion of radionuclides in mother milk. ICRP Publication 95. - 2004. - *Ann ICRP,* 34 (3-4).
13. NRPB. Guidance on the application of dose coefficients for the embryo and fetus from intakes of radionuclides by the mother. – 2005. - *Doc NRPB,* 16 (2).
14. HPA. Guidance on the application of dose coefficients for the embryo, fetus and breastfed infant in dose assessments for members of the public. *Documents of the Health Protection Agency,* RCE-5. - March 2008.