The experience of individual dose reconstruction after uncontrolled large-scale irradiation of population

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Abstract.

There are three main methods available to obtain retrospective assessments of radiation dose:

a) computational modeling (CM), which use archive monitoring data of radioactive contamination of soils, biota and human body are applied to develop radioecological models for estimation of mean doses. Individualization of mean calculated doses is performed using results of individual questioning of the inhabitants of the contaminated territories. The evaluation of the uncertainty of doses is provided by Monte Carlo method with a variation of parameters of the models;

b) the retrospective luminescence dosimetry (RLD) and c) ESR dosimetry, determine the cumulative absorbed dose in the bricks of buildings and in human tooth enamel, respectively. RLD and ESR dosimetry methods allow the estimation of accumulated dose with accuracy of 20-30 mGy

Estimates of dose obtained by applying CM, RLD and ESR methods downwind the Chernobyl NPP and to Semipalatinsk nuclear test site (SNTS) are overviewed in the paper. The comparisons of dose estimates by different methods are presented.

Key technologies, methods and equipment, application areas, technology target, methods developed, categories of investigated subjects are the following:

Key approaches and technologies. Radioecological models and individual dosimetrical questionnaires for individual dose estimations by modeling calculations (MC), Retrospective Luminescence Dosimetry (RLD) with quartz inclusions, Electron Spin Resonance (ESR) dosimetry with human tooth enamel;

Methods and equipment. RISOE luminescence reader, Brucker ESR spectrometer, know-how spectra processing software, know-how sampling and sample preparation methodology.

Application areas:

-Individual retrospective dosimetry in support to radiation epidemiological studies;

-Retrospective dosimetry in support to making decision regarding mitigation of the health consequences of large scale radiation accidents;

-Retrospective dosimetry in a case of local radiation accidents with radioactive sources;

-Retrospective instrumental estimation of radiation doses in a cases of uncontrolled (accidental) irradiation of personnel or patients in a course or radiation therapy.

Target: to develop and to harmonize the system of methods of retrospective dosimetry for national and worldwide distribution.

Methods developed: radioecological models and individual dosimetrical questionnaires for individual dose estimations by modeling calculations; retrospective luminescence dosimetry with quartz inclusions in the bricks of the buildings; retrospective ESR dosimetry with human tooth enamel.

Categories of investigated subjects: Population of territories contaminated following the Chernobyl accident (Russian Federation) – Fig. 1.; Population of territories around Semipalatinsk nuclear test site (Russian Federation and Republic of Kazakhstan)- Fig. 2.

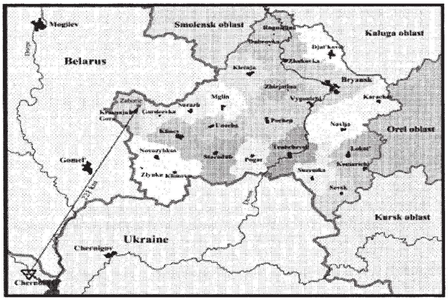


Fig.1. Example [1,2]. Map with indication of raions of Bryansk oblast (Russian Federation), which were contaminated resulting the Chernobyl accident. 221 km of distance from Chernobyl NPP to the most contaminated settlement - Zaborie village (soil contamination density by ^{137}Cs - 4300 kBq/m^2).

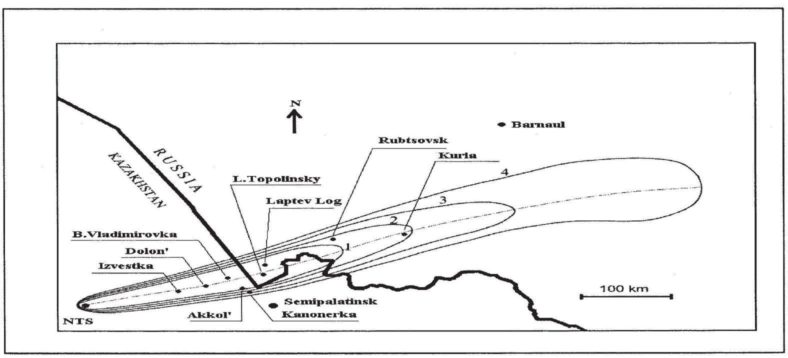


Fig.2. Example [3]. The 1st A-bomb test in former USSR (29.08.1949) – the radioactive trace in Kazakhstan and Russia with indication of investigated settlements. NTS – Semipalatinsk nuclear test site.

Monitoring of ^{131}I activity in thyroid gland and development of thyroid dose reconstruction approach among inhabitants of territories contaminated by radionuclides as a result of the Chernobyl accident (Russian Federation).

During May of 1986 the massive monitoring of ^{131}I activity in thyroid gland among inhabitants of Russian territories contaminated by radionuclides as a result of Chernobyl accident was performed [4,5]. During 3 weeks on May of 1986 26 724 inhabitants of 115 contaminated settlements of 7 subregions (raions) were monitored in Kaluga region (RF) [6]. The detailed description of developed technology of dose monitoring and of methods of thyroid dose estimations are presented in [4,5,7]. Individual thyroid doses were estimated for each monitored person with accounting for real dose forming factors on May of 1986 year [6]. As to Kaluga region, the maximal thyroid doses were estimated in 3 contaminated subregions – Ul'ianovoskiy, Zhsizdrinskiy, Khvastovochskiy (see Table 1 as well for 7 investigated subregions in total [5]).

It was found on the early stage of investigation (1986 year) that statistical distribution of individual thyroid doses is characterized by "long tail" in the individual dose range, which is much higher than mean and median doses for different age groups [4].

Table 1. Example [5]. Thyroid absorbed doses in different age groups of investigated inhabitants of 7 subregions of Kaluga region.

Values*)	Thyroid absorbed doses for different age groups, mGy. (age groups, years, are related to the moment of the accident)					
	<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
DM, mGy	31	26	14	10	8.3	8.1
GSD	2,7	2,7	2,6	2,4	2,7	2,7

*) N-number of investigated persons; MID-maximal individual dose; DA-average dose for given age group; DM-median dose for given age group; GSD- geometric standard deviation.

The results of massive monitoring of thyroid doses among inhabitants of contaminated territories of Kaluga region were combined with the similar data related to contaminated territories of Bryansk region (Russia) and Republic of Belarus. As a result the individual thyroid dose reconstruction approach was developed for persons who were not monitored just after the accident (on May, 1986): it is radioecological semiempirical model and individual dosimetrical questionnaires for individual dose estimations by modeling calculations [4,5,7-10].

The developed approach of individual thyroid dose reconstruction is still actual for implementation in a cases of possible large scale radiations accidents.

Figure 3 shows an example of comparison of individual thyroid doses: calculated individual thyroid doses VS dose estimations based on the results of ^{131}I measurements in thyroid gland among inhabitants of contaminated territories of Bryansk region are presented [7].

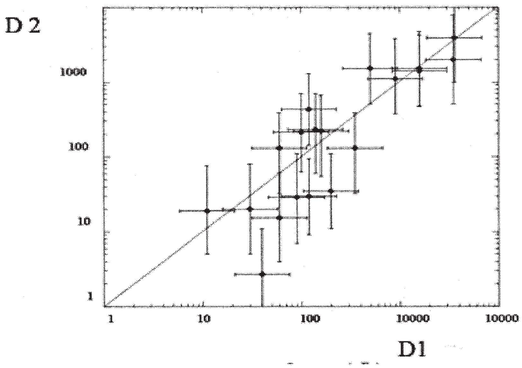


Fig. 3. An example [7] of comparison of individual thyroid doses: calculated individual doses (D 2, mGy) VS dose estimations based on the results of ^{131}I measurements in thyroid gland (D 1, mGy) among inhabitants of contaminated territories of Bryansk region.

Monitoring of ^{137}Cs activity in whole body and development of whole body internal dose reconstruction approach among inhabitants of territories contaminated by radionuclides as a result of the Chernobyl accident (Russian Federation).

Starting from the fall of 1986 year till 2001 year the massive monitoring of ^{137}Cs activity in whole body among inhabitants of Russian territories contaminated by radionuclides as a result of Chernobyl accident was performed [11]. The detailed description of methodology developed and equipment used are presented in [12].

The results of massive monitoring of ^{137}Cs activity in whole body were applied for developing of approach of individual whole body dose reconstruction for persons who were not monitored: it is radioecological model and individual dosimetrical questionnaires for individual dose estimations by modeling calculations [13].

The developed approach of individual whole body internal dose reconstruction is still actual for implementation in a cases of possible large scale radiations accidents.

As in a case of thyroid gland irradiation, it was found that statistical distribution of individual whole body doses of internal irradiation is characterized by “long tail” in the individual dose range, which is much higher than mean and median doses [12].

Figure 4 shows an example of statistical distribution of individual whole body doses of internal irradiation among inhabitants of contaminated territories of Bryansk region.

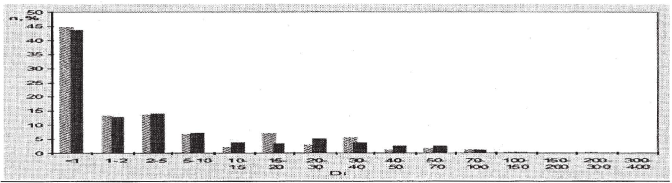


Figure 4. Statistical distribution of individual whole body doses of internal irradiation (Bryansk region).

On the horizontal axis (Di , mSv):

Results of estimation of individual whole body doses of internal irradiation on the base of ^{137}Cs activity measurements in whole body of inhabitants of contaminated territories of Bryansk region - whole body doses accumulated during 15 years after the Chernobyl accident (total number of monitored persons - 34 834);

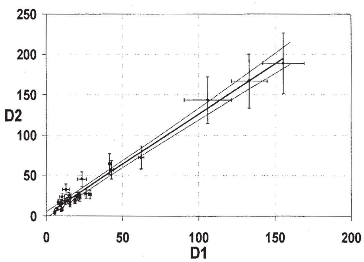
Results of estimation of individual whole body doses of internal irradiation on the base of developed approach of dose reconstruction (radioecological model and individual dosimetrical questionnaires) - whole body doses accumulated during 15 years after the Chernobyl accident (total number of questioned persons – 1 456);

On the vertical axis n,%:

Percentage from total number of persons with available results of ^{137}Cs measurements (total number of these persons – 34 834)

Percentage from total number of personsn with available individual questionnaires (total number of these persons – 1 456)

Figures 5 and 6 shows an examples of comparison of individual whole body doses of internal irradiation: calculated individual doses VS dose estimations based on the results of ^{137}Cs measurements in whole body among inhabitants of contaminated territories of Bryansk region are presented. Comparisons were performed for the same persons, which have data of ^{137}Cs measurements and data of individual questioning as well. Figure 5 – 1st year after the accident ($D2 = (1.24 \pm 0.25) \times D1 + 1.7 \pm 2.1$; $R=0.98$, $p<0.01$). Figure 6 – 15th year after the accident ($D2 = (1.02 \pm 0.15) \times D1 + 0.12 \pm 0.41$; $R=0.94$, $p<0.01$).



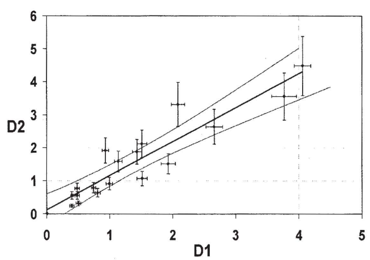


Fig 5.

Fig.6.

Retrospective luminescence Dosimetry (RLD).

RLD employs the measurement of termo- or optical stimulated luminescence from quartz in bricks. The intensity of this luminescence is proportional to dose of external irradiation. This enables the absorbed accumulated dose due to external irradiation to be measured [1-3].

International intercomparison of RLD.

International intercomparison of RLD was performed for quartz inclusions extracted from the brick's samples of buildings in Zaborie village, Bryansk region (Russia) contaminated by Chernobyl fallout (Fig 7). Data of four Labs are presented in figure 7 - RF, UK, Germany, Finland [1,2].

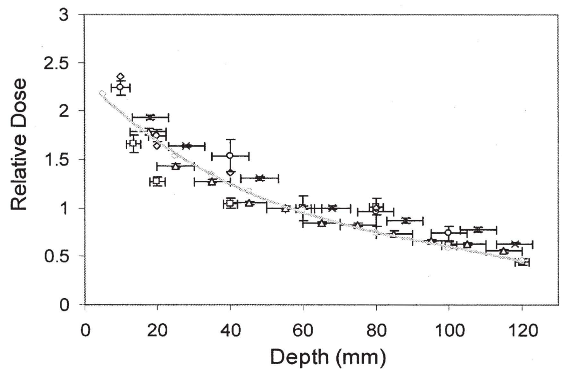


Fig.7. Example [1,2]. Results of international intercomparison: depth-dose profile in the brick's sample from Zaborie village (former textile facility), Bryansk region, Russia. Background accumulated dose is subtracted. "Age" of building is equal to 29 ± 2 years at the moment of sampling. Background accumulated dose is equal to 73 ± 7 mGy. Maximal accumulated accidental dose (during 12 years after Chernobyl accident) in the brick at the depth from the wall surface 10 mm is equal to 302±36mGy. Accumulated dose in the air near the sampling point was estimated to be equal 515±80 mGy. Soil contamination density by ^{137}Cs in the sampling point is equal to 4460 ± 340 kBq/m^2 (in 1986 year).

International intercomparison of RLD method was performed as well for 4 brick samples extracted from 3 locations (former school, former small Church, former big Church) in Dolon' village (Kzakhstan), which is the most affected populated settlement as a result of the 1st A-bomb test of the former USSR on 29 August, 1949 (see Table 2 [14-18]).

Table 2. Example [14-18]. Results of international intercomparison of RLD method near Semipalatinsk nuclear test: estimation of accumulated dose in the brick at 10 mm depth averaged over four samples from three locations in Dolon' village (background dose is subtracted).

RLD method of dose estimation*)	dose in the brick at 10 mm depth, mGy**)	references
TL	249±42	[16]
Tl/OSL	204±15	[14,15,18] ***)
OSL	210±120	[17]

*) TL – thermo stimulated luminescence; OSL – optical stimulated luminscence.

**)In order to estimate accumulated dose in the air multiply to 2.0±0.2.

***)Averaged over 4 Labs.

Evaluation of potential of RLD.

Figure 8 shows example of results of measurements of accumulated dose in air VS ^{137}Cs soil contamination density in different locations of Bryansk oblast, Russia [1,2, 19].

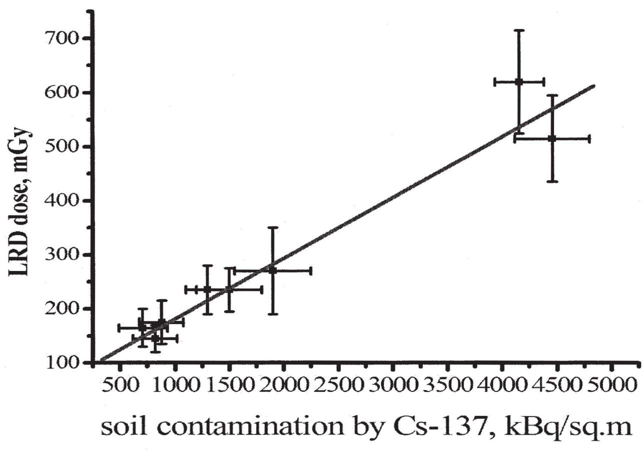


Fig. 8. Example [1,2,19]. Results of measurements of accumulated dose in the air VS ^{137}Cs soil contamination density in different locations of Bryansk oblast, Russia. Dose estimations were performed in 1998 year (R=0.97).

Figure 9 shows an example of comparison of RLD dose in the air (external irradiation) with calculated dose for several locations in St. Vishkov village, Bryansk oblast, Russia [1,2,19].

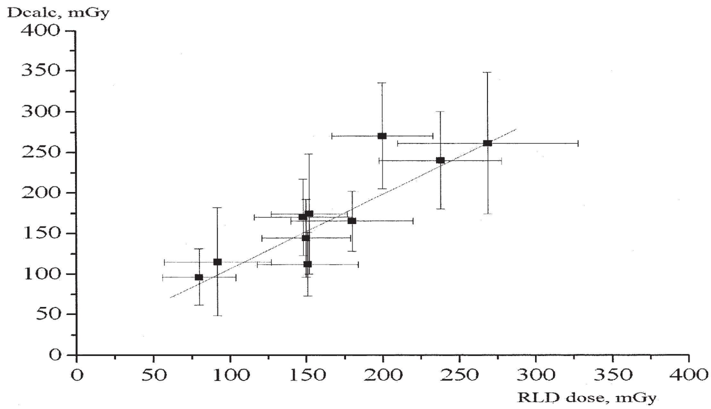


Fig. 9. Example [1,2,19] of comparison of RLD dose with calculated dose for locations in St. Vishkov village, Bryansk oblast, Russia (R=0.86).

Results of RLD dose estimations (dose in air) for settlements in the vicinity of the trace of 1st former USSR nuclear test (1949 year) are presented in Table 3 [3].

Table 3. Example of RLD dose estimation for some settlements in the vicinity of the trace of 1st former USSR nuclear test (1949 year) [3].

Territory	RLD dose (in the air), mGy
Kazakhstan: Dolon'	475±110
Kanonerka	225±60, 250±60
Akkol'	less than 20 mGy
B. Vladimirovka	less than 20 mGy
Izvestka	less than 20 mGy
Altai Krai, Russia: Topolinskiy	230±60

It should be noted that LRD dose for Dolon' village is in a good agreement with the results of computed dose: LRD dose is equal to 475±110 mGy [3] and computed dose is equal to 645±70 mGy [18]. According to [20,21] the computed dose is equal to ≈ 500 mGy.

Retrospective ESR dosimetry with human tooth enamel.

Tooth enamel mainly consists from nonorganic crystal fraction of hydrooxiapatite. As a result of irradiation the stable paramagnetic centers are forming in the crystal fraction. The concentration of these centers is determined by ESR method [22-25].

The international intercomparison of ESR tooth enamel dosimetry method was performed among 20 Labs. The irradiation of tooth samples by unknown nominal doses was performed by IAEA. SD between nominal doses and ESR doses determined by MRRC is equal to 32 mGy (Figure 10).

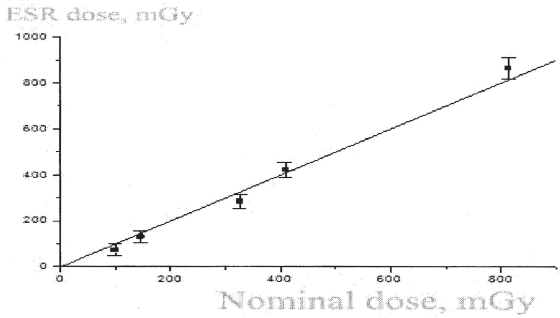


Fig.10. Retrospective ESR tooth enamel dosimetry: international intercomparison: result of MRRC participation are presented.

ESR dosimetry: evaluation of potential.

Figure 11 shows the correlation between individual doses determined by ESR method and calculated doses for Zaborie village (Bryansk region, Russia) contaminated after the Chernobyl accident [19].

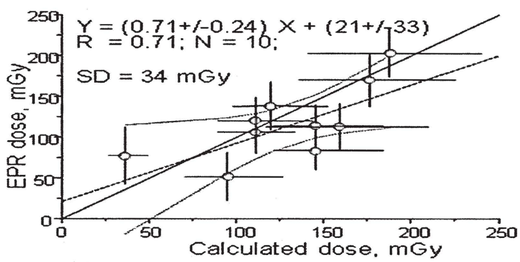


Fig. 11. Example [19]. Accumulated individual doses determined by ESR method VS calculated individual doses for inhabitants of Zaborie village (Bryansk oblast, Russia). SD between two methods is equal to 34 mGy.

ESR doses in Dolon' village near Semipalatinsk nuclear test site are presented in Table 4.

Table 4. Example. Accumulated doses (from 1949 year till 2000 year) among inhabitants of Dolon' village near Semipalatinsk nuclear test site determined by ESR tooth enamel method are presented. Background dose is subtracted.

ESR dose, mGy	number of samples	references
165±22	11	[22]
177±33	3	[23]
45	2	[24]
ESR dose overall average: 156±37 mGy (n=16)		

Current results.

Three independend methods of dose reconstruction (computational modeling, RLD, ESR) were overwieved. Instrumental mehods are in good agreement with computational modeling.

Sensitivity of RLD and ESR methods is about 20-30 mGy of accumulated dose. It is possible to reconstruct accumulated dose at least 50 years after irradiation.

Possible future implementation of potential of retrospective dosimetry methods:

To establish international collaboration and Nonformal International Virtual Laboratory of Retrospective Dosimetry for a cases of possible large scale radiation accidents.

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