Brief analysis of the calculated mean effective doses, which had been accumulated by the residents of the settlements of the Russian Federation affected by radioactive contamination due to the accident at the Chernobyl NPP in 1986 for the period from 1986 through 1995

The contamination of the territory of Russia with radioactive materials due to the Chernobyl accident started on April 28, 1986 as a result of changing the direction of the wind blown over the Chernobyl area to the northeast on April 27, 1986. Due to the intensive rainfall over the boundary between the Mogilev, Gomel oblasts of Belarus and the Bryansk oblast of Russia that occurred on April 28-29, 1986 when the radioactive cloud moved over the territory, the Bryansk-Belarus "spot" was formed (1, 5). On average, one day later, on April 29-30, radionuclides were deposited in a similar way and probably from the same cloud in the territory of Kaluga, Tula and Oriol oblasts. The maximum level of the radioactive contamination of the territory in the Tula-Kaluga-Oriol "spot" was lower by an order of magnitude than that of the Bryansk-Belarus "spot". It is suggested that was due to the extension and exhaustion of the cloud as a result of previous depositions (1, 4-8). Nevertheless, the level of radiation exposure to the population of the three oblasts especially in 1986 had been taken into account by the national and local authorities when decisions concerning radiation protection were made. The decisions were based on information from intensive radiation monitoring carried out from May 1986 by central and local bodies and institutions affiliated to Goskomgidromet of the USSR (State Committee of Hydrometeorology of the USSR), Ministry of Public Health of the Russian Federation and Gosagroprom (State Committee of Agricultural Industry) (1, 2, 4, 8, 9).

From the beginning of the radioactive fallout the population was exposed to external and internal radiation from a mixture of various fission products and activation products. Radioisotopes of iodine and cesium, as well as strontium and plutonium, were the most significant contributors. Radiation monitoring involved the estimation of the density of contamination of the soil by long-lived radionuclides, such as ^{137}Cs, ^{90}Sr and isotopes of plutonium, in the settlements and surrounding territories. Their concentration in air was measured as well. The radionuclide composition was studied, the dose rate from γ-radiation was measured, foodstuffs and water were tested for existence of radioactive radionuclides, and content of radionuclides in a human body was measured. All this information enabled one to estimate the current annual doses to the population. This estimate was necessary for making decisions. It was very difficult to estimate radiation doses that accumulated in the first year after the accident. At that time dozens of radionuclides were sources of radiation, each of which had different radiological properties. Temporal changes of the radiation situation were rapid and depended on local environmental and social conditions (1-5, 7-9).

Table 1 consists some important characteristics of the radionuclides that arrived at the territory of the Russian Federation as a result of atmospheric transfer.

Table 1. Characteristics of the principal radionuclides deposited to the territory of Russia following the Chernobyl catastrophe (7, 10).

Radionuclide				Half-period		Final stable isotope
Mother (m)	Type of radiation	Daughter (d)	Type of radiation	T_m	T_d	
^{137}Cs	β	^{137m}Ba	β+γ	30.2 g	2.55 min	^{137}Ba
^{136}Cs	β+γ	–		13.1 day	–	^{136}Ba
^{134}Cs	β+γ	–		2.06 g	–	^{134}Ba
^{131}I	β+γ	–		8.04 day	–	^{131}Xe
^{132}Te	β+γ	^{132}I	β+γ	78.2 h	2.3 h	^{132}Xe
^{133}I	β+γ	^{133}Xe	β+γ	20.8 h	5.25 day	^{133}Cs
^{140}Ba	β+γ	^{140}La	β+γ	12.74 day	40.27 h	^{140}Ce
^{95}Zr	β+γ	^{95}Nb	β+γ	63.98 day	35.15 day	^{95}Mo
^{103}Ru	β+γ	^{103m}Rh	β+γ	39.28 day	56.1 min	^{103}Rh
^{106}Ru	β	^{106}Rh	β+γ	368.2 day	3 s	^{106}Pd
^{141}Ce	β+γ	–		32.5 day	–	^{141}Pr
^{143}Ce	β+γ	^{143}Pr	β+γ	33 h	13.56 day	^{143}Nd
^{144}Ce	β+γ	^{144}Pr	β+γ	284.3 day	17.3 min	^{144}Nd
^{125}Sb	β+γ	^{125m}Te	β+γ	2.77 g	58 day	^{125}Te
^{99}Mo	β+γ	^{99m}Tc	β+γ	66 h	6.04 h	^{99}Ru

At the end of the decade after the Chernobyl accident the development of recommendations for reconstruction of the dose accumulated by the population for the whole period of exposure was completed. The document “Reconstruction of the mean effective dose to the population of the settlements of the Russian Federation affected by radioactive contamination as a result of the accident at the Chernobyl NPP that had been accumulated during the period 1986-1995” was developed in 1996 by specialists of the Institute of Radiation Hygiene of the Ministry of Public Health of the Russian Federation (St.-Petersburg), Medical Radiological Research Center of Russian Academy of Medical Sciences, State Research Center of the Russian Federation - Institute of Biophysics, Scientific and Productive Association “Typhoon” of Roshydromet (10). The document (10) was approved as methodical recommendations 2.6.1.579-96 by the Department of Goskomsanepidnadzor of the Ministry of Public Health of Russia.

The mean accumulated effective dose in the settlements of the Bryansk, Oriol and Tula oblasts of Russia was calculated by specialists of the Institute of Radiation Hygiene of the Ministry of Public Health of the Russian Federation (St.-Petersburg) (composition of the team of specialists was given below); in the settlements of the Kaluga oblast the calculation was made by the specialists of the Medical Radiological Research Center of the Russian Academy of Medical Sciences, the specialists of the State Research Center of the Russian Federation (Institute of Biophysics) calculated doses in Ryazan and Lipetsk oblasts.

The mean accumulated effective doses were calculated for residents of 1091 settlements of the Bryansk, 1489 settlements of the Tula, 1038 settlements of the Oriol and 404 settlements of the Kaluga oblasts. According to reports of the Goskomhydromet in these settlements the mean density of soil contamination with ^{137}Cs exceeded 37 Bq/km^2 (1 Ci/km^2). No limitations for the level of density of soil contamination with ^{137}Cs were made for the calculation of the dose in 721 settlements of the Ryazan and 142 settlement of the Lipetsk oblasts.

Mean accumulated effective dose were estimated in order to justify the preventive measures addressed to the population which were based on the “Concept for radiation, medical and social protection and rehabilitation of the accidentally exposed population of the Russian Federation” (11). The important task of the job was to deliver the information on radiological consequences of the Chernobyl accident to the population and local authorities. This was done.

With some limitations the estimated mean accumulated effective dose can be applied to the prognosis for delayed health effects of the Chernobyl accident on the population of the affected oblasts of the Russian Federation. It is important to note that the thyroid dose from radioiodine was not included in the calculation of the mean doses that are given in the tables.

Method for dose reconstruction

General information

The models and algorithms for the calculation of doses accumulated by residents are based on experimental investigations conducted over many years in the settlements of Bryansk, Tula, Oriol and Kaluga oblasts of Russia. These are the oblasts with the highest concentration of radionuclides after the Chernobyl accident (2, 9,12-16). The reconstruction of the mean accumulated effective dose (MAED) in the years 1986-1995 by the residents of six oblasts of Russia has been accomplished according to the Methodical Recommendations of Minzdrav (Ministry of Public Health) of the Russian Federation (THE RUSSIAN FEDERATION) (MY 2.6.1.579-96) which determine the requirements of the basic data and of the calculational procedure for estimating MAED of residents of the settlements of Russian Federation exposed to radionuclide contamination from the Chernobyl NNP accident of April 26, 1986 (10).

The mean accumulated effective dose (MAED) averaged over all residents of the settlements is calculated in a conservative way as the mean dose accumulated by the adult population. It was found in earlier dosimetric investigations of residents living near Chernobyl, that the mean dose accumulated in a year by children of various ages did not exceed that of the adult population of the same settlement. The only exception is the dose accumulated in the thyroid, which is due to I-131, and which is higher in children than in the adult population of the same settlements. The dose reconstruction in the thyroid is calculated according to a special procedure documented by the Minzdrav of the Russian Federation.

According to these “recommendations” the mean effective accumulated dose (E) is equal to the sum of the dose due to external gamma radiation E_{ext} and the dose due to internal irradiation E_{int}:

$$E = E_{ext} + E_{int}$$

The radiation monitoring data in 1986-1995 that was conducted in the regions of radioactive contamination due to Chernobyl accident has been used in calculation of MAED. Measures undertaken for the resident protection were taken into consideration. The external radiation dose had been reduced by the special engineering measures in the controlled territory of the Bryansk region. The internal irradiation dose had been diminished by special delivery of “radiation clean” foodstuffs (milk, meat etc) to the controlled Bryansk oblast, by a prohibition to eat “home” animals and homegrown foodstuffs, and by special measures undertaken in agriculture farms in Bryansk, Tula, Kaluga and other regions of the Russian Federation.

In appendixes to MY 2.6.1.579-96 made for several regions of the Russian Federation some peculiarities of the radionuclide contaminations of these regions are listed: the date of radionuclide sediments, their isotope composition, the list of contaminated settlements and figures on density of contaminations by Cs-137 and Sr-90 gathered by “Rosgidromet” as well as information on the volume of monitoring of surroundings and of foodstuffs, on measurements of radionuclide concentration in the bodies of the residents and on individual doses of external gamma irradiation.

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The radionuclide monitoring data

The database used to reconstruct MAED of the internal and external irradiation of residents of settlements in six oblasts of the Russian Federation for 1986-1995 contain the following information:
. names of regions, villages and settlements, types of settlements and number of residents in each of them according to the1989 census or according to data obtained in the years1985-1986,
. the distribution of residents in different types of buildings (made of wood, one-story buildings, made of brick, many-floor buildings);
. distribution of village and town residents between different social occupations and professions,
. distribution of farms according to the types of soil;
. the times of the beginning and the end of the deposition of radionuclides sediments from the Chernobyl accident in 1986 (10),
. isotopic composition of the radioactive deposition in the oblast or region up to the end of deposition in April 1986 (10)
. the mean density of soil contamination by Cs-137 and Sr-90 in the settlements as it was measured by 1.01 96 (according to “Rosgidromet”(8)),
. data obtained of more than 150,000 measurements of cesium isotopes and Sr-90 content in home made foodstuffs (milk, potatoes etc.),
. data obtained in more than 300 thousand counter measurements of Cs-137,-134 concentration in the bodies of the residents.

Dose of external gamma-irradiation

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The external irradiation dose $E_{ext,}$ includes doses from all deposited radionuclides with lifetimes from several hours to 30 years (Table 1) whose contribution to the dose received in 10 years is bigger than 0.1%. The effective dose of β- and γ- irradiation obtained from radioactive clouds moving over the settlements of the Russian Federation, according to model estimates, is less than 5% of that accumulated during the first year after the accident and is not taken into account in this paper. According to model calculations, the effective dose received from distant and contact irradiation of skin by β-irradiation of radionuclides is small and is not taken into account either

The mean received effective dose by external irradiation of residents in each considered settlement was calculated for the first year after the accident and for following years (up to the end of 1995).

The equation for the effective dose rate during the first year after the accident was calculated by the formula

$$\frac{dE_{i,ext}(t)}{dt} = \frac{dD(t)}{dt} \times C_E \times K_C \times \sum_j L_j(t) \times F_{iJ(t)}$$

mkSv/day,

where ***i*** is the number of adults in a particular group;

dD(t)/dt is the dose rate received in the air at the height of 1 meter above an open virgin strip of ground, mkGy/day;

C_E is the transition coefficient from the dose received in the air to the dose of adult people. It is equal to 0.75 mkSv/mkGy;

K_C is a coefficient describing the reduction of effective dose by the snow layer. It is equal to 0.8 for the time interval from November 1 to March 31 and to 1 for all other months;

L_j takes into account the difference between virgin ground and the typical ground in the settlement;

The sum is take over all radionuclides **j**

F_{ij} is part of time when residents of group *i* spend in *j*-type part of the settlement. The L_j and F_{ij} values are given in (10) for various seasons of the first post-accident year.

When calculating the dose from external irradiation for the second time interval (1<t<9.7 years), we only took into account the gamma radiation from Cs-137 and Cs-134. The contribution of gamma radiation of all other radionuclides (Ru-106 ~ 1%, Sb-125 ~ 1%) was neglected. The dose changes very slowly with time, and we only used year-averaged values of F_{ij} for the calculations.

We used in the calculations official demographic data on the number of residents living in houses of different types. In the villages we considered two types of buildings only: one-story buildings made of wood and of brick. If there were many-floor houses we considered the doses as if their residents lived in one-story buildings. In town-like settlements and in towns the part of the residents living in many-story buildings had been taken into account. To make the calculations easier, we calculated the following specific values of mean effective doses of external irradiation

[mkSv/(kBq*m^{-2}) for Cs-137] for the residents of three types of settlements:

<u>for village settlements</u>

. dose accumulated during the first year after the accident,

. dose accumulated during next years (up to 1995) if the engineering deactivation is not taken into account;

. dose accumulated during next years (up to 1995) if the engineering deactivation <u>is</u> taken into account (for Briansk oblast only);

<u>for town-like settlements</u>

. dose accumulated in the first year after the accident;

. dose accumulated during next years (up to 1995)

<u>for towns</u>

. dose accumulated in the first year after the accident;

. dose accumulated during next years (up to 1995)

For several resettled settlements in Gordeevsk, Zlynkov, Krasnogorsk and Novozybkov regions of Bryansk oblast the data had been calculated up to the time of resettlement: 09.01. 1986 for Barsuki, Progress, Knyazewschina, and Nizhnyaja Melnica in Krasnogorsk region, and up to 01.01.1990 or 01.01.1992 for other 40 villages, according to Bryansk oblast administration data.

Internal irradiation dose

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The algorithms used for reconstruction of the internal dose are different for the first year after the accident (04.29.86 – 04.30.87) and for the next time period because of the different formation processes. The doses are caused by ^{134}Cs, ^{137}Cs, ^{90}Sr and ^{89}Sr that mostly enter with homemade foodstuffs.

In the first period, during the first two to four months after the Chernobyl accident, the level of "surface" contamination of vegetable and animal foodstuffs by the *j*-th radionuclide contamination in the middle strip of Russia was, mostly, connected with the density σ_j of soil contamination by this isotope and by meteorological factors of its deposition. The concentration of the *j*-th radionuclide of cesium and strontium C_{jm} in the milk of cows grazing in contaminated districts can be approximately calculated by the formula:

$$C_{jm}(t) = KP_{jm}(0)*\sigma_j(t)*(\exp(-\ln2*t/T_2)-\exp(-\ln2*t/T_2)), \text{ Bq/l},$$

Where $KP_{jm}(0)$ is the initial (at t=0) coefficient of the transition of the of *j*-th isotope into cow's milk after contamination of the surface soil and of vegetables, m^2/kg(l);

T_1= 2 d is the half-life of cesium and strontium removal from cow's milk.

T_2 =15 d is the half-life of removal of contamination from the vegetables that comprise cow food.

Beginning in autumn 1986 and for a long time there afterwards, the main significance of the radionuclide transition into vegetables was through their root system. The dependence of "root" KP on the type and on agrochemical characteristics of the soil where foodstuffs and animal food is grown had been established. On turf-podzol soils, the "root" KP of Cs-134,-137 into vegetable and animal foodstuffs diminished during the years 1986-1991 with 1-1.5 year period. Beginning in 1991-1992 the KP of Cs-134, -137 became gradually smaller and in 1993-1995 was not observed at all. Beginning in 1987 the Sr-90 transition coefficient into foodstuffs diminished with a 5-7 year period.

In all internal dose calculations we prefer those based on SICH data. The quantity of these measurements was especially large during the first 5 years after the accident when the main contribution to the total dose was accumulated. When these data are absent or insufficient, the dose is estimated from the data on radionuclide content in foodstuffs responsible for the main contribution to dose (milk and potatoes). If their quantity is inadequate or if they are not reliable, the radioecological model must be used. This model is based on transition coefficients of radionuclides from soil into foodstuffs (10).

According to the Methodical Recommendations (10), in dose calculations for residents of towns of oblast or region subordination (TOS) and (TRS) and of (TLS) the data obtained in SICH measurements are preferable and if they are absent the data are used which are obtained in analyses of milk and potatoes in the shops (TOS) and in small private farms (TRS and TLS). If these data are absent as well, it is considered that town and TLS residents consume foodstuffs with the same radionuclide content as in agricultural settlements of the region.

The internal irradiation doses of the residents during the period from the second to the tenth years after the accident had been calculated by summation of year doses due to local foodstuff consuming containing radionuclides of three types: Cs-137, Cs-134 and Sr-90. The program of computer calculations for every year looked first for the data of SICH measurements. If these data were absent it looked for data of Cesium and Strontium radionuclide content in local foodstuffs. If the measured data were enough in one year, they were used for that year and also for the previous and for the following years. If the data of both types did not contain information needed for calculations, the program takes the data on soil type used for farming and estimates coefficients of radionuclide transition into milk and potatoes using the data of the table 3.2 of reference (10).

Results of the reconstruction of the mean accumulated effective dose

Table 2 gives summarized data related to 6 contaminated oblasts of the Russian Federation, in which mean accumulated effective doses have been already calculated.

It is seen from the table 2 that in about 50% or more (Ryazan and Lipetsk oblasts respectively) of the dose accumulated during 9.7 years had been accumulated during the first year after the accident. The ratio between maximal and minimal values of the mean accumulated effective dose is ranged between 14 (the Oriol oblast) and 42 (the Bryansk oblast).

Estimates of the dose values show that in the Bryansk oblast the mean dose accumulated during the 9.7 years is within the range of 4 mSv to 167 mSv. In 27 settlements the accumulated dose exceeded 70 mSv, which value has been proposed as a criterion for the estimation of the degree of the radiation effect on the population. In the Tula oblast there was not one settlement with a mean accumulated effective dose above 70 mSv. In one settlement of the Arsenievsky rayon of the Tula oblast the mean dose accumulated for 9.7 years was only 33 mSv. In 160 settlements of that oblast the mean accumulated effective dose is within limits of 10 mSV to 30 mSv. In the Oriol oblast there was not a settlement with accumulated effective dose that exceeded 30 mSv.

In the settlements of the Kaluga oblast the maximum value of the mean effective dose accumulated for 9.7 years after the accident is 25 mSv. In the Ryazan and Lipetsk oblasts the dose is considerably less than that in the other oblasts given in Table 2. However, the doses averaged for a settlement of all of the oblasts, except for the Bryansk oblast, distinguish at the less extent. More details concerning the value of mean accumulated effective dose to the adult population of the settlements are given in relevant tables of this issue.

Table 2. Summary of the results of the calculation of the mean effective doses in contaminated oblasts of the Russian Federation accumulated in the first year after the accident and during the 9.7 years subsequent to the accident at the Chernobyl NPP.

Oblast	Number of settlements	Mean effective dose accumulated in the first year, mSv				Mean effective dose accumulated for 9.7 years, mSv			
		Mean	Standard deviation	Minimal	Maximal	Mean	Standard deviation	Minimal	Maximal
Bryansk	1091	11.4	9.5	2.4	80	23.5	19.2	4	167
Kaluga	404	3.0	2.3	0.7	12	6.3	4.9	1.4	25
Tula	1489	2.6	1.5	0.7	10.4	5.5	3.7	1.6	33
Oriol	1038	2.2	0.9	0.7	8.1	4.4	2.5	1.7	23
Ryazan	721	2.4	1.2	0.2	8.0	3.9	1.9	0.3	9.8
Lipetsk	142	2.1	0.8	0.3	5.1	3.2	1.1	0.4	7.9

The work was carried out in 1995-1997 on the basis of contracts granted by the Ministry of Emergency of Russia and the Ministry of Public Health of Russia.

The teams of experts who estimated the mean accumulated effective dose were:

Bryansk, Tula and Oriol oblasts:

Institute of Radiation Hygiene of the Ministry of Public Health of Russia (St. Petersburg)

Prof. P.V.Ramzaev, Director

Dr. M.I.Balonov, Head of Department; Dr. V.Yu.Golikov, Leading Researcher; Dr. G.Ya.Bruk, Leading Researcher; Dr. V.N.Shutov, Head of Laboratory; Dr. A.B.Bazyukin, Senior Researcher; Dr. I.A.Zvonova, Leading Researcher; Dr. I.G.Travnikova, Leading researcher; Dr. T.V.Zhestko, Researcher; Mr. A.Yu.Vlasov, Researcher

Branch of the Institute of Radiation Hygiene of the Ministry of Public Health of Russia (Town of Novozybkov, the Bryansk oblast)

Dr. V.I.Kovalenko, Director

Dr. V.I.Parkhomenko, Head of Department; Dr. M.V.Kislov, Senior Researcher; Dr. A.V.Ponomarev, Senior Researcher

Central Department of Epidemiological Surveillance of the Bryansk oblast

Dr. P.A.Stepanenko, Chief Physician

Dr. E.N.Shaposhnikova, Head of the Department of Radiation Hygiene; Dr. I.S.Kaplun, Chief Physician of the Novozybkov branch; Dr. V.A.Vasilevitsky, Hygienist of the Novozybkov branch; Dr. O.P.Ignatova, Chief Physician of the Klintsy branch; Dr. S.E.Krivenko, Hygienist of the Klintsy branch

Central Department of Epidemiological Surveillance of the Tula oblast

Dr. A.G.Lobkovsky, Chief Physician

Dr. D.S.Kotik, Head of the Department of Radiation Hygiene; Dr. A.S.Kornilov, Hygienist

Central Department of Epidemiological Surveillance of the Oriol oblast

Dr. Yu.A.Odintsov, Chief Physician

Dr. S.A.Milovanov, Head of the Department of Radiation Hygiene, Dr. S.N.Poteyev, Hygienist

Kaluga oblast:

Medical Radiological Research Center of Russian Academy of Medical Sciences, Obninsk

Academician of RAMS A.F.Tsyb, Director

Dr. V.A.Pitkevich, Head of Laboratory; Dr. O.K.Vlasov, Leading Researcher; Dr. I.K.Khvostunov, Senior Researcher; Mrs. N.V.Shchukina, Researcher

Ryazan and Lipetsk oblasts:

State Scientific Center - Institute of Biophysics, Moscow

Academician of RAMS L.A.Ilyin, Director

Dr. M.N.Savkin, Deputy Director; Dr. M.P.Grinev, Head of Department; Dr. A.V.Titov, Senior Researcher; Dr. A.N.Lebedev, Senior Researcher; Dr. A.V.Gordeyev, Senior Researcher.

Department of Sanitary and Epidemiological Surveillance of the Ministry of Public Health of Russia

Mrs. G.S.Perminova, Head of Department

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