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DATABASE OF METEOROLOGICAL AND RADIATION MEASUREMENTS MADE IN BELARUS DURING THE FIRST THREE MONTHS FOLLOWING THE CHERNOBYL ACCIDENT

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Abstract

Results of all available meteorological and radiation measurements that were performed in Belarus during the first three months after the Chernobyl accident were collected from various sources and incorporated into a single database. Meteorological information such as precipitation, wind speed and direction, and temperature in localities were obtained from meteorological station facilities. Radiation measurements include gamma-exposure rate in air, daily fallout, concentration of different radionuclides in soil, grass, cow's milk and water as well as total beta-activity in cow's milk. Considerable efforts were made to evaluate the reliability of the measurements that were collected. The electronic database can be searched according to type of measurement, date, and location. The main purpose of the database is to provide reliable data that can be used in the reconstruction of thyroid doses resulting from the Chernobyl accident.

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Availability of the database for using by Third Party is limited to qualified investigators under collaborative agreement with the Republican Center of Radiation Control and Environmental Monitoring (Minsk, Belarus).

Keywords

Chernobyl; meteorological; radiation; measurement; database

1. INTRODUCTION

As a result of the Chernobyl accident in north-western Ukraine on 26 April 1986, large amounts of radionuclides (fission products, activation products, and fuel material) were released into the atmosphere and caused serious contamination in Belarus, Ukraine, and Russia (UNSCEAR 2000). Large-scale investigations of the environmental contamination by radioactive materials have been conducted by international organizations since the time of the accident (EC 1998; IAEA 2006a, 2006b). The contamination of air, soil, surface water and ground water with long-lived radionuclides (^{137}Cs, ^{90}Sr, and ^{238,239,240}Pu) was analyzed in those studies. At the national scale, the contamination of the Belarusian territory with long-lived radionuclides has been also investigated thoroughly (CHB 1996). Fig. 1 illustrates the ^{137}Cs deposition density in Belarus (CHB, 2001). The collected and analyzed measurements of long-lived radionuclides also form the basis for the prediction of the environmental contamination with these radionuclides of Chernobyl origin in subsequent years (UNSCEAR 2008).

Analysis of the environmental contamination with short-lived radionuclides during the first few months after the accident has received less attention, although most of the exposure to population was due to radioiodines, and resulted mainly from the consumption of milk contaminated with ^{131}I. It is estimated that several thousand Belarusian children and adolescents received thyroid doses from ^{131}I of 2 Gy or more (UNSCEAR 2000) and that the thyroid doses exceeded 10 Gy for a few hundreds of them (Shinkarev et al 2008). The substantial increase of thyroid cancer beginning in 1990 among children who resided in areas contaminated with ^{131}I in fallout from the Chernobyl accident seems to be the major health effect resulting from the accident (WHO, 2006).

The estimation of the thyroid doses from intakes of ^{131}I is largely based on measurements of exposure rate against their neck (called “direct thyroid measurements”) that were performed on large numbers of people within a few weeks after the accident; the methodology used does not make it necessary to know the absolute concentrations of ^{131}I in milk or in other foodstuffs (Likhtarev et al. 2006). There are, however, major uncertainties in this type of dose assessment. In the framework of a long-term epidemiological study of thyroid cancer and other thyroid disease in Belarus following the Chernobyl accident conducted jointly by the Ministry of Health of Belarus and the U.S. National Cancer Institute (Stezhko et al., 2004), it has been found desirable to use an independent approach, called the “environmental transfer approach”, in order to evaluate and confirm the validity of the thyroid dose estimates derived from direct thyroid measurements. In this “environmental transfer approach”, the transfer of ^{131}I to man, and, consequently, the thyroid dose, is modeled using as a starting point the ^{131}I concentrations in air and soil, and making use also of other parameters, such as exposure rates, ^{131}I concentration in pasture grass, in cow’s milk, and/or in leafy vegetables (Bouville, 1999). The valid implementation of the “environmental transfer approach” required calibration of this method with measurements of ^{131}I activity in environmental samples.

In addition, other contributions to the thyroid dose (e.g. inhalation and ingestion of short-lived radioiodines and radiotelluriums, external exposure from radionuclides deposited on the ground, and ingestion of cesium isotopes), which were minor compared to ^{131}I intakes, are being estimated (Gavrilin et al. 2004; Minenko et al. 2006; Drozdovitch et al. 2010).

External exposure to the thyroid resulted from the ground deposits of gamma-emitted radionuclides: short-lived radionuclides with half-lives of less than 10 d (^{99}Mo, ^{132}Te, ^{131}I, ^{132}I, ^{133}I), medium-lived radionuclides with half-lives of 10 to 100 d (^{95}Zr, ^{95}Nb, ^{103}Ru, ^{136}Cs, ^{140}Ba+^{140}La, ^{141}Ce), and long-lived radionuclides with half-lives of more than 100 d (^{106}Ru, ^{134}Cs, ^{137}Cs, ^{144}Ce). Internal whole-body exposure to the population was caused mainly by ingestion of ^{134}Cs and ^{137}Cs. Reconstruction of radiation doses from these pathways requires the knowledge of the mixture of radionuclides at the time of their ground deposition in various locations of Belarus.

Fortunately, a large number of radiation measurements of short- and medium-lived radionuclides in air, soil, grass, cow's milk, and water were performed in Belarus during the first few months after the accident. To keep these measurements and make them available for the purposes of the reconstruction of thyroid doses at the present time and in the future, it was decided to create a database of meteorological and radiation measurements performed shortly after the Chernobyl accident. This paper describes those radiation measurements, which have been collected, entered, validated and stored in an electronic database.

In addition, it was found important to collect and include in the electronic database the meteorological measurements, because of their direct influence in the timing, location, and magnitude of the activities deposited on the ground after the accident. The meteorological and the radiation measurements will be presented and discussed in turn.

2. METEOROLOGICAL MEASUREMENTS

Meteorological data were collected at a number of locations in Belarus. The network of the State Committee for Hydrometeorology for the entire country includes 56 meteorological stations, 82 stationary meteorological posts, 47 hydrological posts, and 88 so-called "expedition" posts. The locations of the 56 meteorological stations in the entire country are shown in Fig. 1. The figure also shows the 26 stationary posts located in the Gomel and Mogilev oblasts[1], which were the most contaminated oblasts of Belarus.

Meteorological information, such as precipitation, wind speed, wind direction, and temperature, is important for the reconstruction of radionuclide transport in the atmosphere and deposition onto ground surfaces (Cederwall and Peterson 1990). Following the Chernobyl accident, the meteorological data were used in a model of atmospheric transport to calculate the ^{137}Cs and ^{131}I air and ground contamination at a large number of locations in Ukraine (Talerko 2005a, 2005b). Because the same approach was intended for the calculation of ^{131}I deposition in Belarus, it was very important to collect all meteorological information available in the country for the time period of 10 days when the major releases of radioactive materials occurred; for reasons of consistency with the radiation measurements, the period of data collection was extended to 31 July 1986, that is, about three months following the accident..

Wind speed and direction, and temperature were measured four times per day (at 6, 9, 18 and 21 h) at the 56 meteorological stations using standard methods and procedures (SCH, 1985). The air temperature was measured at a height of 2 m, while the wind characteristics (average wind speed, average wind direction, maximal wind speed every 10 minutes and maximal wind speed during 3 hours of observation) were measured on a meteorological platform 10–12 m above the ground level by means of an anemometer, namely M-63M-1. Wind speed (up to 60 m s^{-1}) and direction (with an uncertainty of ±10 degrees) were

[1]An oblast is the largest administrative unit in Belarus. The typical size of an oblast is 30,000–40,000 km^2 with a population of 1.1–1.5 million persons. There are six oblasts in Belarus; their borders are shown as thin lines in Fig. 1. The oblasts are sub-divided into raions; typically, there are ~20 raions of similar size and population in one oblast.

averaged automatically every 10 minutes of measurements. Maximal wind speed for every 10 minutes was also estimated. The information that is recorded in the database consists of the daily average wind speed and direction as well as the average, minimal and maximal temperatures observed during the day.

Precipitation was measured four times per day (at 6, 9, 18 and 21 h) at the 56 meteorological stations and twice a day (at 9 and 21 h) at the 82 stationary posts and at the 47 hydrological posts, and daily, from midnight to midnight of the following day, at the 88 expedition posts. Fig. 2 shows the geographical pattern of precipitation over the territory of Belarus on 28 and 29 April, 1986 which were the days of most intensive fallout. It should be noted that daily (from midnight to midnight of the following day) precipitation amounts are shown for the meteorological stations and for the expedition posts. For the stationary and hydrological posts, the precipitation amounts are shown for the time period from 21 h of the previous day until 21 h of the reported day.

It is interesting to compare the maps of ^{137}Cs deposition (Fig. 1) and of rainfall (Fig. 2). According to literature data (Orlov et al. (1992), Borzilov and Klepikova (1993)), the Gomel-Mogilev cesium spot (which consists of the northern part of the Gomel Oblast and the southern part of Mogilev Oblast) was due to rainfall of up to 20 mm that occurred in that region on 28–29April 1986 (Fig. 2) and led to wash-out of radioactivity from the passing plume producing an area highly contaminated with ^{137}Cs. The other highly contaminated area near the reactor site is mainly due to dry deposition soon after the accident. In the northern part of the country, rainfall on 28–29 April did not result in noticeable ^{137}Cs fallout, presumably because the radioactive cloud did not travel that far north during those days.

In addition to information on rainfall amount, detailed characteristics of the precipitation events, such as thunderstorm, shower, normal rain, dew, fog, etc., observed in the vicinity of the 56 meteorological stations were collected. This additional detailed information was used to improve the precision in the calculation of the radionuclide activities deposited on the ground[2]. The type and intensity of the precipitation event were defined visually; the duration of the event is defined as the difference between its times of beginning and end within the day. The meteorological events and the degree of their intensity were coded according to the list and descriptions of the events recommended by the World Meteorological Organization (SCH 1985). The numbers of meteorological measurements that were collected for Belarus for the time period from 26 April to 31 July 1986 are given in Table 1, along with the descriptions of the precipitation events that occurred during the same period.

3. RADIATION MEASUREMENTS

Radiation measurements were organized in Belarus within a few days after the Chernobyl accident, with the purpose of monitoring the level of radioactive contamination of the environment, with special attention given to humans and foodstuffs. Radiation levels are still monitored to this day, although with a lower degree of intensity. Four time periods are considered: (1) from 26 April to 31 July 1986, corresponding approximately to the first three months after accident; (2) 1 August 1986 to 31 December 1986; (3) 1 January 1987 to 31 December 1988; (4) 1 January 1989 to date.

The results of the radiation measurements performed in the following media during the first time period are included in the database:

- Exposure rate in air

[2]N. Talerko. Personal communication. Kiev, 2008.

- Radionuclide concentrations in air and in fallout
- Radionuclide concentrations in soil, grass, milk, and water samples
- Total beta-activity measurements in milk.
- ^{131}I concentrations in milk, which were derived from the total beta activity measurements.

3.1. Exposure rate in air

Before the Chernobyl accident, measurements of exposure rate in air were made routinely once a week at 11 locations in Belarus. The measurements were made at a height of 1 m above ground level with a military dose-rate meter, called DP-5, equipped with a Geiger-Mueller detector. Exposure rate was measured and recorded in units mR h^{-1}. The minimal indication of the DP-5 device is 0.05 mR h^{-1}.

After the accident, the number of locations with exposure-rate measurements and the frequency of measurements were increased. By 1 May 1986, measurements of exposure rate were conducted a few times per day at 21 meteorological stations, including two towns highly contaminated with Chernobyl fallout, Bragin and Chechersk in Gomel oblast. By 10 May 1986, exposure rates were measured at 25 meteorological stations. By the end of June 1986, exposure rate was routinely measured up to seven times per day at 34 meteorological stations. The results of all 6,051 measurements made by means of the DP-5 device until the end of July 1986 are included in the database (Table 1).

The variation with time after the accident of the exposure rates measured in Bragin, Gomel and Pinsk is shown in Fig. 3. As can be seen from the figure, during the first few days after the accident, an exposure rate of 20–30 mR h^{-1} was measured in Bragin where the average ^{137}Cs deposition density was 840 kBq m^{-2}. Bragin is located 45 km north of the Chernobyl nuclear power plant. Exposure rates of 1 to 2 mR h^{-1} were measured shortly after the accident at the more distant locations: Gomel (130 km north-east of Chernobyl; ^{137}Cs deposition density: 90 kBq m^{-2}) and Pinsk (280 km west of Chernobyl; ^{137}Cs deposition density: 20 kBq m^{-2}) (Fig. 1).

3.2. Air concentration

Before the Chernobyl accident, air sampling was made routinely every day in Belarusian Center of Hydrometeorology and Control of Environment (current name is Republican Center of Radiation Control and Environmental Monitoring, Minsk) with unit (brand 19TTS-48 with a flow rate of 3000 m^3 h^{-1}) that sampled aerosols at 1 m above ground level. Total beta-activity of aerosols was measured in Minsk while spectrometry was done in Scientific and Production Association Typhoon (Obninsk, Russia).

The same unit was used after the accident for daily sampling. Samples were sent to Obninsk for gamma-spectrometry. Database contains results of measurements of aerosols in air samples which carried out from 26 April to 16 May 1986. Unfortunately, samples obtained during the first few days after the accident were measured only on May 6 and later when short-lived radionuclides, in particular ^{133}I and ^{132}Te+^{132}I, gone from sample due to radioactive decay.

3.3. Daily fallout

Daily fallout was collected at 8 meteorological stations: three in Brest oblast (Brest, Baranovichi and Pinsk), and one in the capital of each of the other five oblasts (Gomel, Grodno, Minsk, Mogilev, and Vitebsk). At each location, fallout was passively collected on 0.3 m^2 sheets of gauze placed horizontally at 1 m height above ground level. The gauze was changed every day at 8 h in the morning and sent by plane to the Scientific and Production Association Typhoon (Obninsk, Russia) for radionuclide analysis. In Obninsk, the gauze samples were cut into four pieces of equal area and part or all of the material was compacted into 46-mm or 76-mm diameter pellets. The samples were measured for times ranging from 60 to 3600 seconds with a gamma-spectrometer equipped with a semi-conductor detector, namely DGDK-50A. The energy range of the DGDK-50A detector is from 50 keV to 3.0 MeV with an energy resolution of 7 keV at 1.332 MeV.

Fallout samples were routinely collected before the accident at all eight meteorological stations mentioned above. The numbers of daily fallout measurements in each oblast after the Chernobyl accident are given in Table 1. Daily measurements of ^{131}I were obtained at all of the eight meteorological stations. In 41–50% of the samples, ^{95}Zr, ^{103}Ru, ^{134}Cs, ^{137}Cs, ^{141}Ce, and ^{144}Ce were measured while ^{95}Nb, ^{140}Ba, and ^{140}La were measured in 31–40% of the samples collected mainly before 15 May 1986 at the meteorological stations located in Brest and Gomel oblasts. In some locations and for a few days, ^{106}Ru, ^{132}Te, ^{136}Cs, and ^{239}Np also were detected. Fig. 4 shows the variation with time of daily fallout of selected radionuclides in the city of Gomel. Table 2 provides ratios of activities of ^{131}I-to-^{137}Cs in daily fallout measured in five locations where activities of both ^{131}I and ^{137}Cs were measured.

3.4. Radionuclide concentrations in soil, grass, milk, and water samples

To obtain a large number of data relevant to the fallout-grass-milk pathway that is largely responsible for the thyroid dose from intakes of ^{131}I, a wide-scale campaign of collection of samples of soil, grass, and milk was organized in Belarus shortly after the Chernobyl accident. Soil and grass samples were taken in villages as well as in natural landscapes. Criteria for soil sampling sites were horizontal, flat, uniform, open, undisturbed soil surface located at a distance of not less than 2 heights of surrounding buildings and no closer than 20 m from unpaved roads. Before sample collection, the exposure rate in air was measured at heights of 2–5 cm and 1 m above the ground. Samples were collected only if the results of these two measurements did not differ by more than 50 percent as large difference between these two measurements may reflects non-uniformity of deposition on sample site. The grass samples were taken from the surface of the soil samples. Water samples were collected in rivers and lakes.

All soil samples were collected to a 5-cm depth using 140-cm or 150-cm diameter rings or 10cm×10cm and 20cm×20cm frames. Soil samples were taken according to the "Instruction for sampling of soil during evaluation of radioactive contamination of area" developed by the State Committee for Hydrometeorology of the USSR. It should be also noted that soil samples were taken not for research purposes but within the framework of a wide-scale rapid monitoring of the radioactive contamination of large areas in Belarus. According to the instruction, 5-cm deep soil sample was determined to be enough to capture the majority of the activity of freshly deposited radionuclides. Published results support the validity of that assumption: Ivanov et al. (1997) showed that in 1987 from 94% to 100% of ^{137}Cs activity was located in top 5-cm layer of soil; Straume et al. (1996) showed that seven years after the accident (in May 1993) from 83% to 98% of the Cs-137 activity is still located in the top 5-cm layer of soil on undisturbed sites; one to two months after the Fukushima-Dai-ichi accident, Kate et al. (2012) found that in area with cumulative precipitation of 89 mm, 96% of total radiocesium and 100% of total ^{131}I inventories in soil profile were contained in the top 5 cm depth. Therefore, we believe that that practically all of the activity deposited on the ground was captured in the 5-cm deep soil samples collected within 3 months after the Chernobyl accident.

The gamma-spectrometric measurements made in Belarus from 5 May through 31 July 1986 that were collected, verified and kept in the database include radionuclide concentrations in about 6,200 soil samples, 563 grass samples, 154 cow's milk samples, and 57 water samples (Table 1). These samples were collected in the most contaminated areas of Gomel and Mogilev Oblasts shortly after the accident and later on (in June-July 1986) in less contaminated areas of Belarus. Fig. 5 shows the locations where soil samples were taken. The majority of soil samples were taken in the most contaminated Gomel (65%) and Mogilev (26%) oblasts. Samples were collected by different Belarusian organizations, with two thirds of the samples collected by the Institute of Nuclear Power Engineering (Minsk, Belarus; current name is Joint Institute for Power and Nuclear Research - Sosny). Non-Belarusian organizations also participated in the sample collection: 6% of the samples were collected by the Ukrainian Inspection on Environmental Protection and 5% by the Institute of Biophysics (Moscow, Russia; current name is Burnasyan Federal Medical Biophysical Center).

Most of the measurements (70%) were performed at the Institute of Nuclear Power Engineering (Minsk, Belarus). Many measurements were made by experts from the Institute of Biophysics. Key aspects of the measurements made in the different centers are summarized in Table 3.

Iodine-131 was measured from 5 May through 31 July 1986 in almost 3,300 (53%) of the environmental samples. In almost all samples (95%), ^{103}Ru, ^{134}Cs and ^{137}Cs were measured. Other radionuclides frequently observed were ^{95}Zr (measured in 69% of samples), ^{95}Nb (81%), ^{106}Ru (78%), ^{141}Ce (71%), and ^{144}Ce (56%). The results of measurements of ^{132}Te, ^{136}Cs, ^{140}Ba, and ^{140}La are only available for selected locations and dates (<25% of all samples).

Table 2 provides ratio of activities of ^{131}I-to-^{137}Cs measured in soil sample in Gomel-city where daily fallout was measured. As can be seen from the table, ratio of activities of ^{131}I-to-^{137}Cs measured in daily fallout is consistent with this obtained in soil for that location.

3.5. Total beta-activity in cow's milk

The Sanitary and Hygiene Centers of the former Soviet Union Ministry of Health and the Veterinary Laboratories of the former Soviet Union Agro-Industrial Committee performed measurements of total beta-activity in cow's milk in contaminated areas in Gomel, Mogilev and Brest Oblasts of Belarus in order to restrict distribution of food that was contaminated above the limit established after the Chernobyl accident. The majority of the measurements of radioactivity were made in cow's milk with a beta-radiometer device, namely DP-100, equipped with a Geiger-Mueller detector. This type of detector, which is not energy selective, recorded counts due to the activity of the mixture of radionuclides in the milk.

Table 1 gives the number of cow's milk samples with total beta-activity measured from 29 April through 30 June 1986. For the entire country, total beta-activity in 25,530 milk samples are included in the database. Measurements of total beta-activity in cow's milk were used to derive the ^{131}I activity and to calculate thyroid doses from ^{131}I intakes (Savkin et al. 2004; Drozdovitch et al. 2006). The estimates of ^{131}I activity derived in almost 21,000 results of measurements of total beta-activity in cow's milk also are included in the database.

4. OTHER MEASUREMENTS

4.1. First time period (26 April – 31 July 1986)

In addition to the measurements indicated above, exposure rate against the thyroid gland was measured in April-June 1986 in 130,000 Belarusian persons (Gavrilin et al. 1999) and more than 500,000 whole-body counter measurements of Cs body-burdens in residents of contaminated areas were done in Belarus during post-accident years starting July 1986 (Minenko et al. 2006). These radiation measurements in humans are not included in the radiation database described in this paper and, therefore, are not described in this paper. Database of measurements of exposure rate against the thyroid gland was created by experts from Institute of Biophysics (Moscow, Russia) and is located in this institute. Database with the results of whole-body counter measurements of Cs body-burdens is located in Republican Research Centre for Radiation Medicine and Human Ecology(Gomel, Belarus).

4.2. Second time period (1 August 1986 to 31 December 1986)

Results of measurements that could be helpful to reconstruct the thyroid doses from the Chernobyl accident, not including ^{131}I, which had decayed to negligible levels during the first time period, were also included in the database. The measurements that were considered include radionuclide concentrations (mainly ^{95}Zr, ^{95}Nb, ^{103}Ru, ^{106}Ru, ^{134}C, ^{137}Cs, ^{141}Ce, ^{144}Ce) in 4,955 soil and 169 grass samples.

4.3. Third time period (1 January 1987 to 31 December 1988)

The measurements of ^{106}Ru and ^{137}Cs concentrations in 2,126 soil samples were also included in the database.

4.4. Fourth time period (1 January 1989 to date)

Radiation measurements at meteorological stations and meteorological posts are continuing in Belarus now. The radiation monitoring network includes 55 dosimetric posts where the exposure rate in air is measured; 27 observation points where radioactive fallout from the atmosphere is monitored using horizontal boards that are changed daily; and 7 stations where aerosol samples are collected.

In addition, a radiation surveillance network has been developed to monitor the possible environmental contamination resulting from air trans-boundary transfer of radioactivity from nuclear power plants (NPP) surrounding Belarus (Ignalina NPP is located 4 km from Belarus; Chernobyl NPP – 12 km, Rovno NPP – 65 km, and Smolensk NPP – 75 km). The exposure rate in air is automatically measured at 35 locations, including four Local Response Centers in Mozyr, Mstislavl, Pinsk, and Braslav; three Regional Response Centers in Gomel, Mogilev, and Brest; and the National Response Centre in Minsk. The measured exposure rates are automatically reported sent every 10 minutes to the Republican Center of Radiation Control and Environmental Monitoring.

Wide-scale measurements of long-lived radionuclides such as ^{137}Cs, ^{90}Sr, $^{238, 239, 240, 241}$Pu, and ^{241}Am are also performed in order to evaluate the concentration of these radionuclides and their profiles in different types of soil (Izrael et al. 2009). Information on deposition density of ^{90}Sr and ^{137}Cs measured in 13,556 settlements if Belarus (decay corrected to 1 May 1986) is included in the database.

Iodine-129 and ^{137}Cs were measured in soil samples collected in 1993 and 1997 at 73 sites located in 37 Belarusian settlements (Straume et al., 1996; 2006). These results were also included in the database.

5. VERIFICATION OF THE DATABASE

Because the results of gamma-spectrometric measurements were collected from different organizations from Belarus and other countries, this information was carefully verified. The verification process included the following steps:

1. Revealing of duplicate records. Each record in the database was compared with other records in order to find if there are duplicates. Two records with measurements made in the same place and at the same time were considered to be duplicates if the recorded activities of all radionuclides measured in two samples differed by less than 2%.
2. Because clerical errors occurred when the information was entered by different organizations, all records entered in the database were compared with the information found in the original notebooks where the results of the measurements were recorded. Unfortunately, the original notebooks were found not for all but for around 60% of the data that were collected.
3. For gamma-spectrometric measurements of soil samples the following approach was also applied: the exposure rate measured at a height of 1 m above the ground level on the site where the soil sample was taken was compared with the exposure rate calculated using the results of measurements of radionuclides in soil. The record was considered to be unreliable if the measured and the calculated exposure rates differed by a factor greater than two.

As a result of the verification process, each record in the database was assigned a degree of reliability. Four-thousand nine-hundred ninety-six of 6,233 results of gamma-spectrometric measurements of soil were assigned with degree “reliable” while 1,237 records were assigned with degree “unreliable”, including 373 duplicate records, 383 records with clerical errors that can not be corrected because of absence of the original notebooks, and 481 records that did not satisfy an exposure rate criterion. Four-hundred eighty-three of 563 results of gamma-spectrometric measurements of grass were assigned with degree “reliable” while 80 records were assigned with degree “unreliable”, including 28 duplicate records, and 52 records with clerical errors that can not be corrected. All 154 results of measurements of cow’s milk were found to be reliable. For gamma-spectrometric measurements of water samples, 27 results were assigned with degree “reliable” while 6 duplicate records were found and 9 records have clerical errors that can not be corrected.

6. CONCLUDING REMARKS

This paper describes the meteorological and radiation measurements that were performed in Belarus during the first three months after the Chernobyl accident and were collected from various sources into a single database. The meteorological information was obtained from network of meteorological stations and posts established by the State Committee for Hydrometeorology of Belarus. The radiation measurements include gamma-exposure rate in air, daily fallout, concentration of radionuclides in soil, grass, cow’s milk and water as well as total beta-activity in cow’s milk. This information, obtained from different organizations from Belarus and other countries, was verified and incorporated in an electronic database that is available for a variety of possible uses. These measurements are being used to reconstruct the ground deposition of ^{131}I and other radionuclides to be used in dose reconstruction to population of Belarus exposed to fallout after the Chernobyl accident (manuscript in preparation).

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References

Borzilov, VA.; Klepikova, NV. Effect of meteorological conditions and release composition on radionuclide deposition after the Chernobyl accident. In: Mervin, SE.; Balonov, MI., editors. The Chernobyl Paper. Vol.1. Doses to the Soviet Population and the Early Health Effects Studies. Richland WA: Research Enterprises Inc; 1993. p. 47-68.

Bouville, A. Thyroid dose assessment: an overview of the problems and solutions. In: Thomas, G.; Karaoglou, A.; Williams, ED., editors. Radiation and Thyroid Cancer. World Scientific Publishing; 1999. p. 297-308.

Cederwall RT, Peterson KR. Meteorological modeling of arrival and deposition of fallout at intermediate distances downwind of the Nevada Test Site. Health Phys. 1990; 59:593–601. [PubMed: 2211118]

CHB - Committee for Hydrometeorology of Belarus. Maps of contamination of Republic of Belarus with ^{137}Cs, ^{90}Sr, and ^{238,239,240}. Pu. Minsk; Belgeodezy: 1996.

CHB - Committee for Hydrometeorology of Belarus. Deposition density of ^{137}Cs over the territory of Belarus. Minsk: Belgeodezy; 2001.

Drozdovitch V, Germenchuk M, Bouville A. Using total beta-activity measurements in milk to derive thyroid doses from Chernobyl fallout. Radiat Prot Dosim. 2006; 118:402–411.

Drozdovitch V, Khrouch V, Maceika E, Zvonova I, Vlasov O, Bratilova A, Gavrilin Y, Goulko G, Hoshi M, Kesminiene A, Shinkarev S, Tenet V, Cardis E, Bouville A. Reconstruction of radiation doses in a case-control study of thyroid cancer following the Chernobyl accident. Health Phys. 2010; 99:1–16. [PubMed: 20539120]

EC - European Commission. Atlas on ^{137}Cs deposition on Europe after the Chernobyl accident. Brussels; Luxembourg: 1998.

Gavrilin, YuI; Khrouch, VT.; Shinkarev, SM.; Krysenko, NA.; Skryabin, AM.; Bouville, A.; Anspaugh, L.; Straume, T. Chernobyl accident: reconstruction of thyroid dose for inhabitants of the Republic of Belarus. Health Phys. 1999; 76:105–119. [PubMed: 9929121]

Gavrilin Y, Khrouch V, Shinkarev S, Drozdovitch V, Minenko V, Shemiakhina E, Ulanovsky A, Bouville A, Anspaugh L, Voillequé P, Luckyanov N. Individual thyroid dose estimation for a case-control study of Chernobyl-related thyroid cancer among children of Belarus. Part 1: 131I, short-lived radioiodines (132I, 133I, 135I), and short-lived radiotelluriums (131mTe and 132Te). Health Phys. 2004; 86:565–585. [PubMed: 15167120]

IAEA - International Atomic Energy Agency. Report of the Chernobyl Forum Expert Group Environment. Vienna: IAEA; 2006a. Environmental Consequences of the Chernobyl Accident and their Remediation: Twenty Years of Experience.

IAEA - International Atomic Energy Agency. Radiological conditions in the Dnieper River basin: assessment by the international expert team and recommendation for an action plan. IAEA/STI/PUB 1230. Vienna: IAEA; 2006b.

Izrael, YuA; Bogdevich, IM., editors. The Atlas of recent and predictable aspects of consequences of Chernobyl accident on polluted territories of Russia and Belarus (ARPA Russia–Belarus). Moscow–Minsk: «Infosphere» Foundation–NIA-Nature; 2009. p. 140

Ivanov YA, Lewyckyj N, Levchuk SE, Prister BS, Firsakova SK, Arkhipov NP, Arkhipov AN, Kruglov SV, Alexakhin RM, Sandalls J, Askbrant S. Migration of 137Cs and 90Sr from Chernobyl fallout in Ukrainian, Belarusian and Russian soils. J Environ Radioact. 1997; 35(1):1–21.

Kato H, Onda Y, Teramage M. Depth distribution of ^{137}Cs, ^{134}Cs, and ^{131}I in soil profile after Fukushima Dai-ichi Nuclear Power Plant Accident. J Environ Radioact. 2012; 111:59–64. [PubMed: 22029969]

Likhtarev I, Bouville A, Kovgan L, Luckyanov N, Voillequé P. Questionnaire- and measurement-based individual thyroid doses in Ukraine resulting from the Chornobyl nuclear reactor accident. Radiat Res. 2006; 166:271–286. [PubMed: 16808613]

Minenko VF, Ulanovsky AV, Drozdovitch VV, Shemiakina EV, Gavrilin YI, Khrouch VT, Shinkarev SM, Voillequé PG, Bouville A, Anspaugh LR, Luckyanov N. Individual thyroid dose estimates for a case-control study of Chernobyl-related thyroid cancer among children of Belarus. Part II. Contributions from long-lived radionuclides and external radiation. Health Phys. 2006; 90:312–327. [PubMed: 16538137]

Orlov MY, Snykov VP, Hvalensky VA, Teslenko VP, Korneev AI. Radioactive contamination of Belorussian and Russian territory after the Chernobyl accident. Atomnaya Energia. 1992; 72(4): 371–376.

Savkin, M.; Titov, A.; Lebedev, A.; Germenchuk, M.; Bouville, A.; Luckyanov, N. Current status of the study on assessment of ^{131}I specific activity in milk, milk products, and leafy vegetables based on total beta-activity measurements conducted in Belarus after the Chernobyl accident. Full papers of 11th International Congress of the IRPA; 23–28 May 2004; Madrid, Spain. 2004.

Shinkarev SM, Voillequé PG, Gavrilin YI, Khrouch VT, Bouville A, Hoshi M, Meckbach R, Minenko VF, Ulanovsky AV, Luckyanov N. Credibility of Chernobyl thyroid doses exceeding 10 Gy based on in-vivo measurements of ^{131}I in Belarus. Health Phys. 2008; 94:180–187. [PubMed: 18188052]

SCH - State Committee on Hydrometeorology. Guide for hydrometeorological stations and posts. 3-d. Leningrad: Hydrometeoizdat; 1985.

Stezhko VA, Buglova EE, Danilova LI, Drozd VM, Krysenko NA, Lesnikova NR, Minenko VF, Ostapenko VA, Petrenko SV, Polyanskaya ON, Rzheutski VA, Tronko MD, Bobylyova OO, Bogdanova TI, Ephstein OV, Kairo IA, Kostin OV, Likhtarev IA, Markov VV, Oliynyk VA, Shpak VM, Tereshchenko VP, Zamotayeva GA, Beebe GW, Bouville AC, Brill AB, Burch JD, Fink DJ, Greenebaum E, Howe GR, Luckyanov NK, Masnyk IJ, McConnell RJ, Robbins J, Thomas TL, Voillequé PG, Zablotska LB. Chornobyl Thyroid Diseases Study Group of Belarus Ukraine the USA. A cohort study of thyroid cancer and other thyroid diseases following the Chornobyl accident: objectives, design, and methods. Radiat Res. 2004; 161:481–492. [PubMed: 15038762]

Straume T, Marchetti AA, Anspaugh LR, Khrouch VT, Gavrilin YuI, Shinkarev SM, Drozdovitch VV, Ulanovsky AV, Korneev SV, Brekeshev MK, Leonov ES, Voigt G, Panchenko SV, Minenko VF. The feasibility of using ^{129}I to reconstruct ^{131}I deposition from the Chernobyl reactor accident. Health Phys. 1996; 71:733–740. [PubMed: 8887520]

Straume T, Anspaugh LR, Marchetti AA, Voigt G, Minenko V, Gu F, Men P, Trofimik S, Tretyakevich S, Drozdovitch V, Shagalova E, Zhukova O, Germenchuk M, Berlovich S. Measurements of ^{129}I and ^{137}Cs is soils from Belarus and reconstruction of ^{131}I deposition from the Chernobyl accident. Health Phys. 2006; 91:7–19. [PubMed: 16775475]

Talerko N. Mesoscale modelling of radioactive contamination formation in Ukraine caused by the Chernobyl accident. J Environ Radioact. 2005a; 78:311–329. [PubMed: 15511565]

Talerko N. Reconstruction of (131)I radioactive contamination in Ukraine caused by the Chernobyl accident using atmospheric transport modelling. J Environ Radioact. 2005b; 84:343–362. [PubMed: 16024139]

UNSCEAR - United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and effects of ionizing radiation. New York: United Nations; 2000. 2000 Report; Sales No. E.00.IX.4

UNSCEAR - United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and effects of ionizing radiation. UNSCEAR 2008 Report to the General Assembly with Scientific Annexes; Volume II, Annex D. United Nations; New York: 2011.

WHO - World Health Organization. Report of the UN Chernobyl Forum Expert Group “Health”. Geneva: WHO; 2006. Health Effects of the Chernobyl Accident and Special Health Care Programmes.

Highlights

- Meteorological and radiation measurements done after the Chernobyl accident in Belarus were collected
- Data were verified and incorporated into a single database
- Results of this study is being used to improve the thyroid dose estimates after the Chernobyl accident

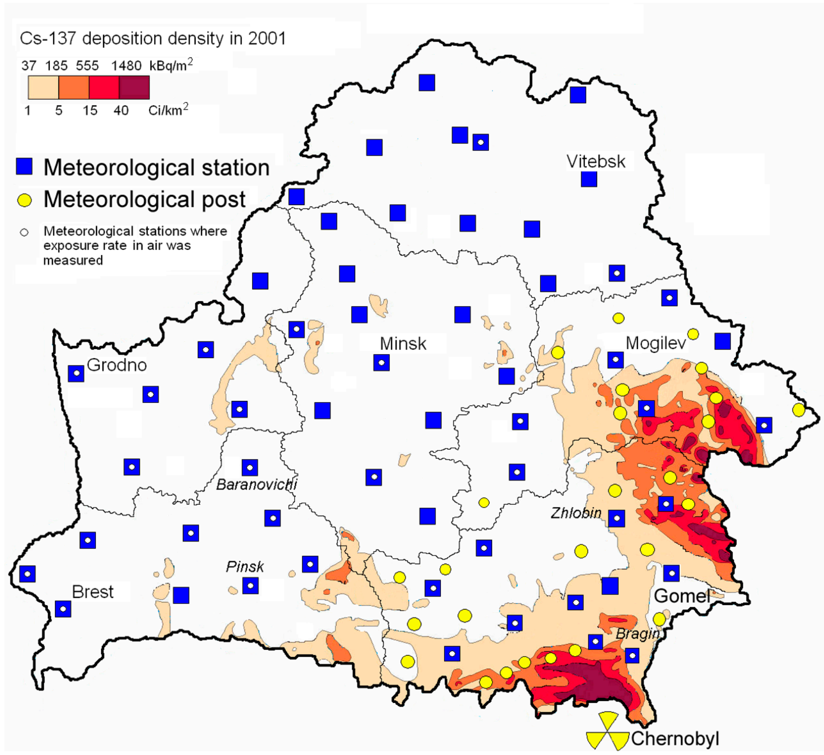

Fig. 1.
Location of 56 meteorological stations in entire country and 26 meteorological posts in the most contaminated Gomel and Mogilev Oblasts. ^{137}Cs contamination of the country is also illustrated.

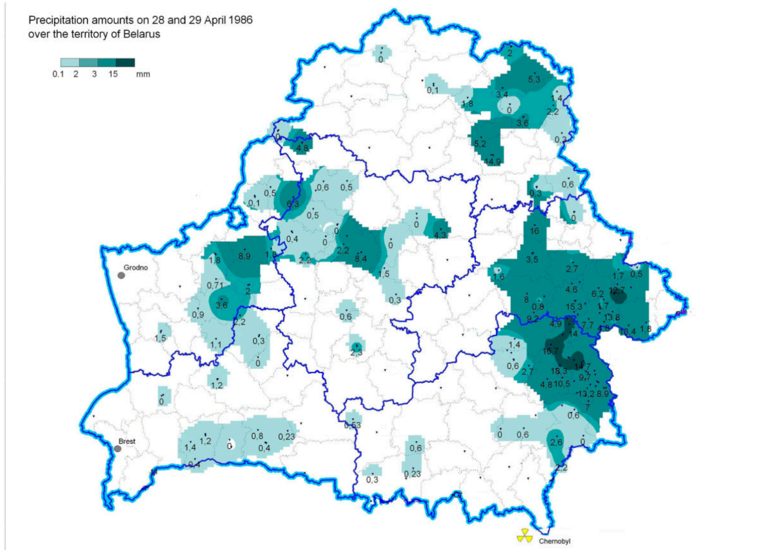

Fig. 2.
Precipitation amounts on 28 and 29 April 1986 over the territory of Belarus.

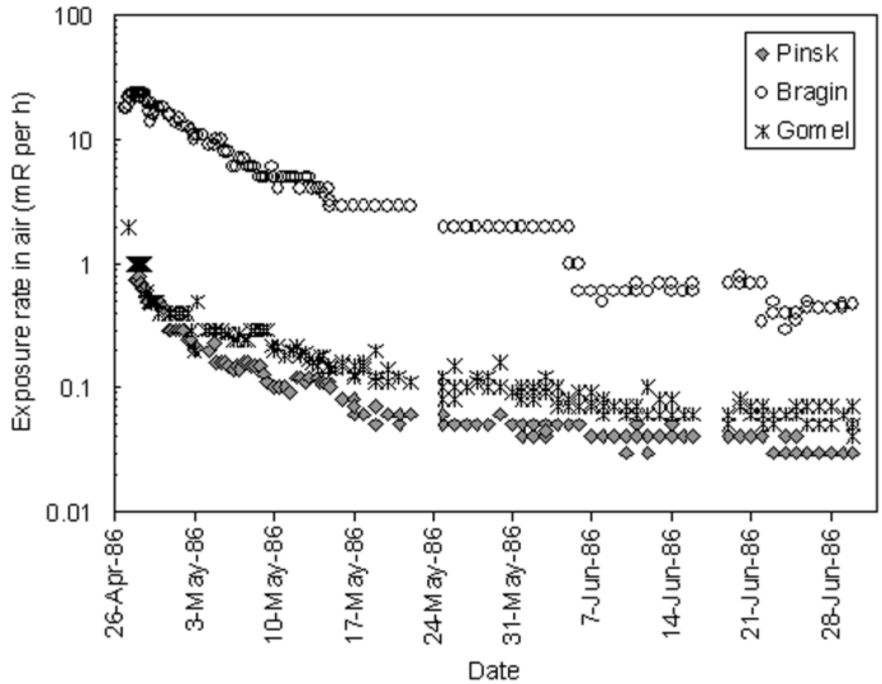

Fig. 3.

Exposure rate in air measured in Bragin (open circle), Zhlobin (closed triangle), and Pinsk (open diamond).

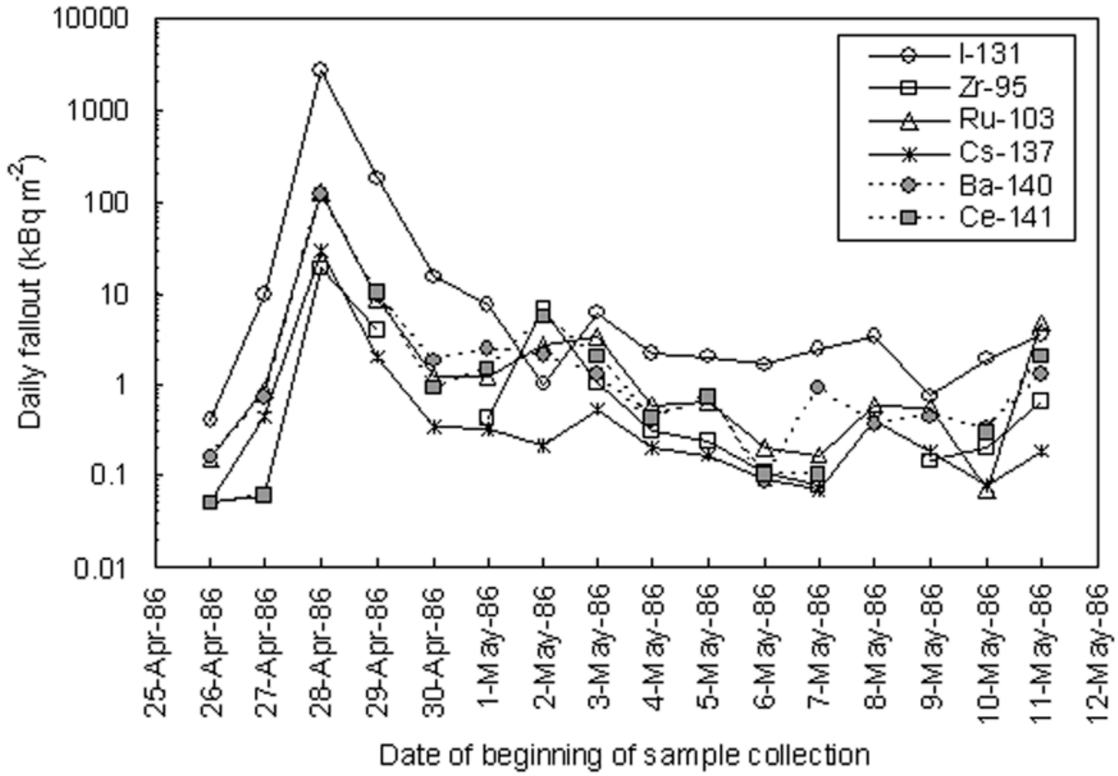

Fig. 4.
Daily fallout (kBq m^{-2}) of selected radionuclides measured in the city of Gomel.

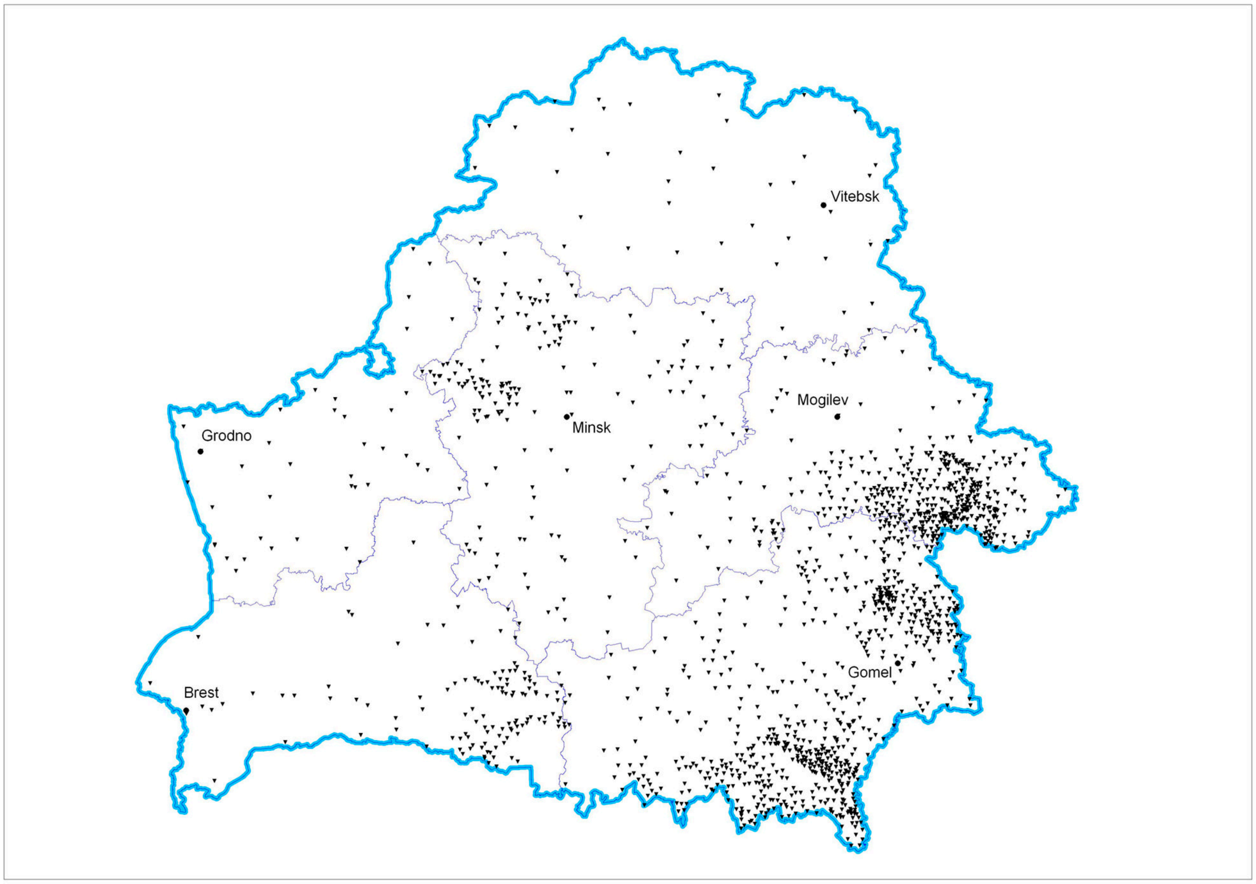

Fig. 5.
Location of sites where soil samples were taken.

Table 1

Number of meteorological and radiation measurements performed in Belarus, 26 April – 31 July 1986.

Type of information	Number of results of measurements performed in						
	Brest Oblast	**Gomel Oblast**	**Grodno Oblast**	**Minsk Oblast**	**Mogilev Oblast**	**Vitebsk Oblats**	**Entire country**
Meteorological:							
Wind[a] and temperature[b]	873	934	582	1,067	582	1,067	5,105
Description of precipitation events	2,237	1745	1,376	2,649	1,599	3,001	12,607
Precipitation[c] observed at							
- Meteorological stations	324	327	211	390	235	414	1,901
- Posts (meteorological, hydrological, expedition)	431	641	221	541	355	415	2,604
- Total	755	968	432	931	590	829	4,505
Radiation measurements:							
Exposure rate in air	1,156	2,385	797	467	1,045	201	6,051
Air concentration	-	-	-	19	-	-	19
Daily fallout of ^{131}I and other radionuclides	77	24	24	25	19	18	187
Gamma-spectrometry measurements[d] of							
- soil	458 (99)	4,025 (2,203)	7 (6)	115 (43)	1,627 (929)	1 (−)	6,233 (3,280)
- grass	33 (13)	330 (230)	13 (12)	19 (15)	168 (83)	-	563 (353)
- cow's milk	4 (4)	130 (129)	6 (6)	8 (8)	6 (6)	-	154 (153)
- water	3 (1)	46 (31)	-	3 (2)	5 (3)	-	57 (37)
Total beta activity in cow's milk[e]	1,142 (768)	22,540 (11,150)	-	-	1,848 (996)	-	25,530 (12,914)
^{131}I concentration in milk derived from the total beta-activity measurements in milk	479	18,838	-	-	1,707	-	21,024

[a] Average for the day

[b] Average, minimal and maximal temperature observed during the day

[c] Number of measurements with non-zero precipitation amounts

[d] Number of records with measured non-zero ^{131}I is given in parentheses.

[e] Total beta-activity was measured through 30 June 1986. Number of measurements done before 1 June 1986 is given in parentheses

Table 2

Ratio of activities of ^{131}I-to-^{137}Cs measured in daily fallout and in soil samples.

Location	Ratio of activities of ^{131}I-to-^{137}Cs measured in					
	Daily fallout			Soil samples[a]		
	N[b]	GM	GSD	N	GM	GSD
Baranovichi	10	22.1	1.3	-	-	-
Pinsk	13	19.6	1.4	-	-	-
Gomel	16	18.0	1.4	9[c]	16.4	2.2
Minsk	10	19.3	1.2	-	-	-
Mogilev	7	14.0	1.4	-	-	-

[a]Decay corrected to 1 May 1986

[b]Number of measurements may be different from number of measurements given in Table 1 as both ^{131}I or ^{137}Cs were not measured in all samples given in Table 1

[c]For Gomel raion

Table 3

Characteristics of gamma-spectrometry measurements performed by different organizations from 26 April to 31 July 1986.

Center performing measurements	Number of measured samples				Gamma-spectrometry detector		
	Total	Soil	Grass	Milk	Detector	Name	Energy range (MeV)
Institute of Nuclear Power Engineering[a]	4,869	4,273	531	65	Ge(Li)	DGDK-50A	0.05–3.0
Institute of Biophysics[b]	700	611	-	89	Ge(Li)	DGDK-40	0.05–3.0
Other organizations	1,263	1,256	7		N.A.[c]	-	-
Unknown	118	93	25	-	N.A.	-	-
Total	6,950	6,233	563	154	-	-	-

[a]Organization (current name is Joint Institute for Power and Nuclear Research - Sosny) is located in Minsk (Belarus).

[b]Measurements were done in Minsk (Belarus) by a team from the Institute of Biophysics (current name is Burnasyan Federal Medical Biophysical Center, Moscow, Russia)

[c]Information on type of gamma-spectrometer used for measurements is not available