SCENARIO I
IPUT RIVER SCENARIO

ABSTRACT

The Iput River scenario is based on measurements made in the highly contaminated Bryansk Region of Russia following the Chernobyl accident in 1986. The density of ^{137}Cs contamination in this area averaged 800,000 Bq m^{-2} and reached 1,500,000 Bq m^{-2} or higher in some local places. The scenario includes agricultural and nonagricultural endpoints and the effects of various countermeasures that were applied in the region. Input information includes measurements of environmental ^{137}Cs in the test area (air concentrations, ground contamination, total deposition, and soil samples/vertical profiles); descriptions of the protective measures taken; environmental information (meteorological characteristics, topographical description, climatic conditions of inland waters and forests); agricultural information (practices by seasons, types of cultivated soils, production and use of feeds); information on agricultural production (foodstuffs); information on the collection of natural products (mushrooms, wild berries, and fish); information on food distribution; and information about the population (age, dwelling and industrial structures, as well as food consumption). Available test data include measurements of ^{137}Cs concentrations in agricultural products (leafy vegetables, potatoes, cereals, hay, milk, beef, pork), nonagricultural food items (mushrooms, wild berries, freshwater fish), and the whole body of humans. Estimates based on measurements are available for daily intake of ^{137}Cs by humans and for external and internal doses. The test data for most endpoints cover a 10-year period. A detailed description of the Iput River scenario is provided along with tables of input data and test data.

INTRODUCTION

The accident at the Chernobyl nuclear power plant on 26 April 1986 was the most serious one on record in nuclear power engineering. The accident led to contamination of vast areas in Europe, across a range of climatic characteristics and economic situations. Measurements collected following the Chernobyl accident have provided a unique opportunity for specialists in radioecological modelling to test the reliability of their models using data on radionuclide contamination of terrestrial and aquatic environments in various regions of Europe. The Iput River scenario is the third “multiple-pathways” scenario developed from post-Chernobyl data specifically for the purpose of testing environmental transport models.

The first two scenarios were used as test exercises during the VAMP (Validation of Environmental Model Predictions) program of the International Atomic Energy Agency. Scenario CB (Central Bohemia) described the post-Chernobyl radioecological situation in Central Europe (IAEA, 1995). The average level of contamination with ^{137}Cs was 5570 Bq m^{-2} (95% confidence interval, 4050 to 7660 Bq m^{-2}), and the test data covered a three-year period (1986–1989). Scenario S (Southern Finland) was more complicated than Scenario CB and included additional pathways, such as aquatic and semi-natural pathways of human exposure to ^{137}Cs (IAEA, 1996). The contamination levels in Scenario S were about 4 times higher than in Scenario CB and amounted to 19,900 Bq m^{-2} (95% confidence interval, 13,900 to 25,900 Bq m^{-2}); the test data cover a five-year period.

Both of these scenarios considered areas far removed from the site of the Chernobyl accident where the ^{137}Cs contamination levels were not high enough to warrant serious agricultural or other countermeasures. In contrast, the Iput River scenario (named for the Iput River catchment area) deals with a heavily contaminated catchment basin and agricultural area in the Bryansk Region of Russia, where the density of ^{137}Cs contamination averaged 800,000 Bq m^{-2} and reached 1,500,000 Bq m^{-2} or higher in some local places.

The Iput River Scenario was initially prepared during the VAMP program and was eventually used as a test exercise by the Dose Reconstruction Working Group of BIOMASS (Biosphere Modelling and Assessment Methods) Theme 2: Environmental Releases (BIOMASS, 2000). The test data for most endpoints cover a 10-year period. The scenario includes agricultural and nonagricultural endpoints and the effects of various countermeasures and is the most comprehensive scenario to date based on post-Chernobyl data.

BACKGROUND

The Iput River catchment basin is located about 200 km to the northeast of the Chernobyl NPP, in the Novozybkov district of the Bryansk Region of Russia (coordinates 52º 30'-40' N, 31º 50'-32º E), in the western part of the country (Figs. 1-3). From the south, the test area is close to Ukraine, and from the west, it is very close to the border of Belarus. Contamination of the test area was caused by the passage of the radioactive Chernobyl cloud from 28 to 30 April 1986. Most of the ^{137}Cs deposition was localized in the middle and lower parts of the Iput River catchment area, hence the name of the scenario. The contaminated area is about 1000 km^2, with a density of contamination up to 1,500,000 Bq m^{-2} or higher in some local places.

Surveys in the areas of Russia across which the radioactive cloud passed after the Chernobyl accident revealed very high contamination of the local area in the Novozybkov district of the Bryansk Region. This local area turned out to be the most highly contaminated area in Russia with respect to ^{137}Cs of Chernobyl origin. Only the most highly contaminated part of the Iput River watershed is considered in the scenario.

The regions of Russia contaminated after the Chernobyl accident are shown in Fig. 1, where the most highly contaminated area is indicated. Data on the contamination of environmental components and on doses to humans in the test area were gathered during the course of systematic investigation carried out by Russian specialists over many years. The Institute of Agricultural Radiology performed measurements and prepared data sets (both input and test data) on contamination of lands and food products. SPA "Typhoon" took measurements of hydrometeorological parameters and contamination of water bodies. The Institute of Radiation Hygiene carried out detailed investigations of radiation doses to the local population, using actual measurements of the ^{137}Cs content in the local residents.

The scenario description which follows provides detailed descriptions of the sampling procedures, measurement methods, and statistical data processing techniques that were used. The following main types of input information are provided:

(1) measurements of environmental ^{137}Cs in the test area (air concentrations, ground contamination, total deposition, and soil samples/vertical profiles);

(2) descriptions of the protective measures taken;

(3) environmental information (meteorological characteristics, topographical description, climatic conditions of inland waters and forests);

(4) agricultural information (practices by seasons, types of cultivated soils, production and use of feeds);

(5) information on agricultural production (foodstuffs);

(6) information on the collection of natural products (mushrooms, wild berries, and fish);

(7) information on food distribution; and

(8) information about the population (age, dwelling and industrial structures, as well as food consumption).

The following types of measurements are available for use as test data:

(1) annual (1986-1996) average concentrations in leafy vegetables, potatoes, cereals (wheat, rye), and animal feeds (hay);

(2) monthly (1986) and quarterly (1987-1996) average concentrations in milk, beef, and pork;

(3) annual (1986-1996) average concentrations in edible mushrooms, wild berries, and freshwater fish;

(4) average concentrations in the whole body of humans (men and women) and distributions of whole body concentrations; and

(5) distributions of individual external doses for reference samples of the population.

In addition, estimates based on measurements are available for the following endpoints:

(1) average daily intake by humans (men and women);

(2) average concentrations in the whole body of humans (men and women) as calculated from estimated intakes;

(3) external dose (cloud and ground exposure);

(4) inhalation dose (cloud and resuspension);

(5) ingestion dose, with a summary of the three principal foods contributing to dose; and

(6) total dose from all pathways.

Some of the measurements or estimates are provided separately for the “controlled” area (where countermeasures were applied) and the “noncontrolled” or “observed” area (where countermeasures were not applied).

INPUT INFORMATION

Environmental ^{137}Cs in the Test Area

Air Concentrations

Practically no experimental data on the ^{137}Cs concentrations in the air of the region are available for the early period after the accident. These concentrations were reconstructed from measurements taken in neighbouring regions and from the air radiation monitoring in the Novozybkov region during the ensuing years (Table 1).

Soil Contamination

The radioactive contamination of the test area was caused by the radioactive "Chernobyl cloud" passage from 28 to 30 April 1986. The radionuclide composition of soil contamination in the early period after the accident is presented in Table 2. Measured ^{137}Cs concentrations in the soil in the settlements of the test area are listed in Table 3 (see also Fig. 4). The vertical distribution of ^{137}Cs in the soil surface layer was determined for different soils in the test area (Table 4).

The Chernobyl fallout in the Bryansk Region of Russia was represented by aerosol particles of condensation type. In contrast, the fallout in the near zone of the Chernobyl NPP was represented mostly by particles with contamination of fuel type. Because of the condensed aerosol nature of the deposition, the share of exchangeable, soluble fractions of ^{137}Cs in soils of the Bryansk Region was rather high in 1987--about 5-6 times higher than that in the Chernobyl near zone. The dominant types of soils in the most contaminated Novozybkov district of the Bryansk Region are soddy podzolic of light mechanical composition (sandy and sandy loam), with a relatively large content of small fractions (the percentage of soil fractions with particle sizes less than 0.05 mm is about 55%). The distribution of ^{137}Cs activity on soil particles of different sizes is given in Table 5.

For the contaminated territory of the Novozybkov district, the values of soil-to-plant transfer coefficients (SPTC) in 1987-1988 were higher than transfer coefficients in the Chernobyl near zone. The maximum values of SPTC were estimated in 1987; they had stabilized in 1988 and became close to the values estimated for global fallout. Since 1988, the SPTC values were rather stable with a slow decrease in time due to the fixation of ^{137}Cs in soil (“ageing” process).

Water Contamination

The Iput River area is shown in Fig. 3. Tables 6-7 provide concentrations of ^{137}Cs in the Iput river water (both in solution and in suspension) during both a flooding period and a low-water period in 1991. Table 8 presents average concentrations of ^{137}Cs in the lake water of the test area. The common properties of these lakes are as follows: depth, about 2 m; area, 0.1 to 0.2 km^2; potassium concentration, 1 to 2 mg L^{-1}; fish productivity, 2 to 5 g m^{-2}. The vertical distribution and specific activity of ^{137}Cs in the upper 20-cm soil layer of the Iput River flood plain and bottom sediments are given in Tables 9 and 10.

The characteristics of the Iput watershed contaminated with ^{137}Cs are presented in Table 11. The coefficient of ^{137}Cs wash-off from the Iput River watershed was estimated to be equal to 1.9 x 10^{-3} y^{-1} in 1987 and decreased to 1.1 x 10^{-3} y^{-1} in 1988. (The wash-off coefficient is defined as the share of the total activity of a watershed that is washed to a river during one year.) The normalized coefficient of ^{137}Cs wash-off from the Iput River watershed was estimated to be equal to 0.8 x 10^{-5} mm^{-1} y^{-1} in 1987, and decreased to 0.6 x 10^{-5} mm^{-1} y^{-1} in 1988. (The normalized wash-off coefficient is defined as the share of the total activity of a watershed that is washed to the river by each millimeter of run-off. The annual run-off layer for the Iput River is about 160-175 mm).

The ^{137}Cs activity in the Iput River water (for each hydrometric post) is correlated closely with the contamination of the particular watershed. The average annual activity of ^{137}Cs in water (near the inflow of the Iput river into the Sozh river) is given in Table 12.

Environmental Information

Meteorological Characteristics

The observations for rainfall in the test area and neighboring regions are given for 5 stations for the period 20 April to 20 May 1986 (Table 13). Total rainfall amounts were measured from 06.00 a.m. on the given day to 06.00 a.m. on the following day and are given in mm d^{-1}. The regional location of the stations is shown in Fig. 2.

The wind direction is unstable in spring: south-westerlies give way to north-westerlies and south-easterlies. The wind speed changes from month to month. In winter, it is insignificant, the maximum occurring in February and being 4 to 5 m s^{-1} on exposed places. In spring and summer it decreases to 2.5 to 3 m s^{-1}. The average annual wind speed in exposed places is 3.5 to 4 m s^{-1}.

Topographical Description

The Iput basin lies in the lowest part of the Pridneprovye lowland. In the upper reaches, the catchment area is a hill plain of 150 to 278 m absolute heights. Rivers and ravines cross the plain. In the middle, the river plain has a few hills of 134 to 233 m absolute heights and is cut by rather shallow river valleys. In the lower reaches, the terrain is plain with prevailing heights of 120 to 150 m (maximum, 188 m). The hills of 20 m have rounded tops and gentle slopes.

The type of soil is primarily loamy sand and sand of 80 to 110 cm in depth. In the lower reaches, it is sand and pebble, loam, and loamy sand; in the river plain it is clay sands. The ground water occurs at a depth of 1 to 3 m and on the slopes of hills, to 10 m.

Hydrological Characteristics of the Iput Basin

The Iput river is 437 km long, with a catchment area of 10,900 km^2. The average slope of the water surface is 0.19%, and the coefficient of river sinuosity is 2.82. Swamps, about 7%, occur largely on the lowland. The lakes are few, most of them on the flood plain. The sand and pebble deposits effectively filtrate precipitation. The predominantly flat relief weakens the intensity of surface run-off and erosion of the Iput River. Most sediments are formed by soil wash-off with down slope snowmelt and rainfall water. The flood plain is mostly two-sided, of 1.5 to 3 km in width. The river bed is meandering, made of sand and silted in pools (Table 14).

The major hydrological characteristics of the Iput river are presented in Table 15. Table 16 shows the water balance of the test region. Month-to-month distributions of discharges of water and suspended sediments to the Iput river are given in Table 17. The fish productivity of the Iput river is about 0.3 g m^{-2}.

Climatic Conditions

The snow cover on the Iput river plain varies significantly. In the coldest time of winter, the air temperature is below –5° C, and stable snow cover is formed. The winter starts early in December and lasts for 3 to 4.5 months. The maximum height of snow cover occurs from the second decade of February to the first decade of March and reaches 30 cm. The snow cover comes off in late March to early April. The daily average temperature increases from 0 to 13 or 14° C during the spring. Given the general tendency of warming, however, spells of cold weather with frosts and snow sometimes occur. The ranges of the average monthly temperatures in the test region are given in Tables 18 and 19.

The test region is distinguished by considerable humidity. The annual amount of precipitation varies from 650 to 790 mm. About 70 to 75% of the total annual precipitation falls during the warm period from April to October. The precipitation is less than 1 mm d^{-1} for about 40% of all precipitation days. Precipitation above 30 mm d^{-1} occurs, on average, once a year; above 20 mm d^{-1}, three times a year; and above 10 mm d^{-1}, 12 to 15 times a year.

Soil Cover

Soddy and soddy-podzolic soils of different bedrock textures predominate. Soils are developed on sands, in some places on loam. The water storage in the soil is directly dependent on its texture. The water storage within the 1-m soil layer is least in sandy and loamy-sandy soils, ranging from 70 to 200 mm. In dry years the water supply can decrease to 20 mm on sands and loamy sands. In spring the formation of run-off is largely dependent on water permeability of frozen soil. The soil freezes down to 40 to 150 cm.

The soils are well described agrochemically. The content of humus in sands and loamy sands is rather low, to 30-40 t ha^{-1} in the 0 to 50 cm layer. The nitrogen content is 4 to 5 t ha^{-1}. About 70% of arable lands have a low to extremely low content of exchangeable potassium, and only 5% have a high content. Soils of medium and strong acidity make up about half the area of the cultivated lands; the rest of the soils have low acidity. Neutral soils make up approximately one-fourth of the cultivated lands, which are located on the drier weak podzolic soil. The primary agrochemical measures are enrichment of light soil with organic matter, application of lime and fertilisers, and reclamation of marshlands.

Forests

The area covered by forest amounts to 2293 km^2 (i.e., 24% of the total area of the district). Average age of the predominant trees, consisting mainly of pine and birch, varies from 37 to 57 years. The forest is primarily mixed (birch, aspen-spruce). In elevated places, it is coniferous. On low and flooded lands, the undergrowth (hazel) is dense and may be up to 3 m high.

The average level of forest contamination is about 980 kBq m^{-2}. The forests in the territory of the test area can be divided into 15 forest units characterised by definite forest type and ^{137}Cs contamination density. The information on the forests related to these forest units is summarised in Table 20. Data on the population living in rural settlements surrounded by forests are also shown.

The most popular mushrooms species sampled by the population are *Boletus edulis*, *Leccinum scabrum*, *Leccinum aurantiacum*, *Suillus luteus*, *Russula* sp, *Cantharellus cibarius*, *Lactarius necator*, *Lactarius terminuses*, *Tricholoma flavovirens*, and *Xerocomus badius.* The berries are represented mainly by *Vaccinium myrtillus*, *Vaccinium vitisidala*, *Rubus idalus* and *Fragaria vesca*. The data on potential yield of the most important species of mushrooms and berries are given in Tables 21-22.

Agriculture

General Characteristics

The test area includes territory of the Novozybkov district of the Bryansk region (Fig 4). The agricultural area (AGRO1) totals about 840 km^2; nineteen farms and 115 inhabited localities are in this territory, with 12,000 inhabitants (Tables 3 and 23). The arable lands occupy about 65% of the agricultural areas, the hay and grazing lands about 35% (Table 24). Each subarea of AGRO1 (Fig. 4) is the territory of one collective farm, including agricultural lands, pasture, meadows, and one or more settlements. Table 25 presents a list of those farms, and Table 26 shows land use on the subareas.

Cultivated Soils

The test area belongs to the Bryansk woodland territory. Topsoil in the area is generally poor turf-podzolic soils with light earth, the soil solution of which is of acidic reaction and has a low absorbing capacity and a poor humus content (Table 27). Agrochemical characteristics for most of the soils are presented in Tables 28-30. The soil types for cereal cultivation are usually chosen as follows:

Winter rye: all mineral soil types are possible;

Winter wheat: light grey forest intermediate loam soil and grey forest light loam soil are the best;

Spring barley: all soils except for peaty swamped and flooded;

Oats: all soil except for peaty ones;

Maize for silage: all mineral soil types, light grey forest and grey forest soil are the best;

Potatoes: all mineral soil types;

Root crops: all mineral soil types;

Vegetables: all mineral soil types except for those with low pH;

Grasses: all soil types.

Practices by Season

Winter and spring grain crops are grown in the region. The sowing of winter crops lasts from August (3rd decade) to September (1st decade). Usually, autumn vegetation is stopped in the middle of October. Its renewal occurs during the first half of April. Generally, harvesting of winter crops is done in July (3rd decade). The sowing of spring grain crops is performed in the second half of April, and harvesting during the last decade of August. Potatoes are planted early in May and harvested at the end of September or early in October. The planting and harvesting of root crops are done 10 days earlier than for potatoes (Table 31).

The major individual types of vegetables include potatoes, beet roots, carrot, marrow squash, cabbage, onion, garlic, tomatoes, and cucumbers. Leafy vegetables are grown mainly in private kitchen gardens.

Vegetation renewal of meadow and pasture herbs occurs in the second decade of April. Usually, they are harvested twice per season, in June (2nd decade) and July (3rd decade). In some cases, depending on weather conditions, there is opportunity for one more hay cutting in September (2nd decade).

Efficiencies of the hay and grass lands in forage production are rather high: wild hay lands provide 0.14 kg m^{-2}, and perennial seeded grass lands provide 0.30 kg m^{-2}. Yields for clover and alfalfa vary from 0.5 to 0.7 kg hay per m^2. Green-cut maize is the main component of silage; its amount is about 4.0 kg m^{-2} (Table 32).

The grazing season begins in May (1st decade) and lasts usually up to the middle of October. The average duration of indoor cattle maintenance is about 170 to 180 days, but it can vary widely from 145 to 200 days (Table 33).

Use of Feeds

To feed animals during their indoor maintenance as well as at the beginning and the end of the grazing season, green-cut forage, hay, silage, root crops, potatoes, and concentrated fodder are used. Feeding rations for cattle vary considerably depending on the feed available at farms. Table 34 gives the feeding rations for bull calves being fattened on a farm in the Novozybkov district where long-term observations were made. The recommended rations for dairy cows and pigs in the test area are shown in Tables 35-36. The rations for hens are presented in Table 37.

Production Output

Low soil fertility and farming efficiency result in rather moderate crop yields (Table 38). Productivity of dairy herds is not high, with the milk yields being 2,000 to 3,000 litres per year per cow. This is due to violations in the feeding rations and insufficient forage supplies at some farms and settlements. The mean milk yield per cow in 1986 is given in Table 39. Slaughter weight of pigs is 80-100 kg, and that of cattle is 400 to 500 kg. In 1986-1996 a decrease in production of grains, potatoes, milk, and meat was registered in the test area. This is due to fact that the land with a ^{137}Cs contamination density of more than 1,480 Bq m^{-2} was not used for agricultural practices. Another reason is attributed to the economic problems.

Contamination of Agricultural Lands

Table 40 presents the general distribution of arable and grazing lands by their contamination density. More detailed information about contamination of agricultural lands is given in Table 41.

Change of Biological Availability and Vertical Migration of ^{137}Cs in Agricultural Soils

Natural geochemical processes and various anthropogenic factors induce some variations in biological mobility of radionuclides and their redistribution along the soil profile of agricultural lands. Data indicate a high immobilization of ^{137}Cs in the absorbing soil complex and its decreased transfer to plants by a factor of 3 to 6 for the period 1987-1990. As a result of vertical migration, the radionuclides move to the underlying soil layers, but at present the major portion of radionuclides occurs in the top (0 to 5 cm) layer. The type of soil and land-tenure are the major factors controlling vertical migration of ^{137}Cs along the soil profile. The largest portion of ^{137}Cs (17.4%) occurs in the top 5 to 10 cm layer of the flood plain meadow (Table 42). The radionuclide distribution is rather uniform along the soil profile during the replowing period of agricultural soils.

Population Information

Sex and Age Distribution

The distribution of the population in the test region by sex and age is given in Table 43.

Reference Data for External Dose Estimation

For the purpose of external dose evaluation, adult rural inhabitants of the test area are classified according to daytime occupation into three groups: indoor workers (accountants, sellers, teachers, economists, librarians, medical staff, industrial workers, office workers, etc.), outdoor workers (machine operators, field workers, cattle- and swine-breeders, drivers, herdsmen, forest workers, carpenters, masons, laborers, etc.) and pensioners (Jacob et al., 1996; Golikov et al., 1999; Balonov et al., 1992; Reconstruction, 1996). The type of house where the people live (one-storey wooden or one-storey brick house) is another relevant parameter. The total number of population groups considered is six. The attenuation factor for 0.66 MeV gamma radiation is 2.1 for one-storey wooden and 8 for one-storey brick houses. The typical size of a house foundation is 7 × 8 meters. The windows comprise about 8% of the vertical outside surface area of a house.

The distribution of the adult rural population of the test area according to the indicated factors is presented in Table 44. Table 45 presents the seasonal average, standard deviation, 5th and 95th percentile values of occupancy factors for three groups of the rural population in the Bryansk region, obtained from 808 responses to a questionnaire in the summer of 1989 in the test region (Jacob et al., 1996). The occupancy factors, in relative units, are equal to the fraction of day time spent by representatives of the population group in the typical location of a settlement or its vicinity. Table 46 presents annual average occupancy factors.

Data for Internal Dose Estimation

Diet for adult rural inhabitants: Table 47 presents typical food rations of adult rural inhabitants in the test area before the Chernobyl accident, according to the data from the poll. Table 48 presents results from interviews of inhabitants of two villages on consumption rates of natural food products (Jacob et al., 1996; Shutov et al., 1993; Bruk et al., 1998; 1999; Reconstruction, 1996) .

Countermeasures implemented after the Chernobyl accident are described below; these countermeasures caused considerable alteration of the food rations of the local population. Tables 49-50 present data from regular polls of inhabitants about their food rations after the Chernobyl accident. Thus, consumption of milk from privately owned cattle by inhabitants of the "Controlled Area" (see next section on countermeasures) fell in the first decade of May by approximately 20%, and in the second decade, by almost half. By the beginning of September the consumption rate was only 20% of the initial level. By the middle of September, after the purchasing of dairy cattle, it fell down to 1% of the initial level. Meanwhile, consumption of "clean" milk from shops increased, but the pre-accident level of total milk consumption was not reached. Consumption of meat from privately owned cattle by inhabitants of the "Controlled Area" had already decreased by almost twice by May, and later it was only 20% of the initial level.

Hunting, fishing, collecting of mushrooms and berries: During the initial period after the accident, the internal doses of the rural population of the investigated region were determined primarily by the consumption of agricultural foods, especially consumption of milk. This group of foods contributed 70-85% of the total intake of ^{137}Cs. The contribution of natural foods in this period constituted only 5-15%. In the later period after the accident, the role of the natural factors increased. Relevant to the use of natural products in these territories are the activities of fishing and hunting, as well as collecting of mushrooms and berries. Only 1-3% of the population engages in hunting.

The data from the poll of the local residents reflect changes in consumption of fish from local pools and of mushrooms (Tables 51-52). In the region, consumption of "nature gifts" strongly decreased after the accident. In villages of the "Controlled Area", consumption of mushrooms and fish fell by a factor of 2 to 5, of berries by a factor of 2 to 3. In the rest of the area ("non-controlled area" or "Observed Area"), consumption of all natural products decreased by a factor of 1.5 to 3.

Countermeasures

General information

Since 1986, a set of long-term countermeasures have been applied in the test area to decrease irradiation of the population (Balonov et al., 1992; Alexakhin, 1993; Reconstruction, 1996). The countermeasures extended to health care and common life (individual protection), as well as to agriculture and forestry. Since May 1986, the inhabitants of the entire contaminated area were encouraged not to consume local animal food products, leaf vegetables and early berries, mushrooms, or fish from local rivers and lakes. Also, they were encouraged to spend vacations outside the contaminated area. Besides that, it was proposed to re-dig private kitchen gardens, to introduce lime, manure and mineral fertilisers, and to stop cultivating some crops (for example, legumes), that most intensively accumulate cesium radionuclides. It was also recommended that methods of cooking meals be changed: wash and clean vegetables thoroughly, cook poured off soups, soak mushrooms, etc.

Thorough washing of fruit and berries decreased ^{137}Cs activity by approximately 10%, washing of table greens, up to 60%, and soaking of mushrooms, by 50%, on average. Also, the population was proposed to subject to radiometric monitoring food products from private plots and "nature gifts" (mushrooms, berries and local fish). All food products coming to shops and markets were monitored by the bodies of the State Sanitary Inspection in accordance with the standards adopted by the Ministry of Health of the USSR, the temporary permissible levels (TPLs; see Table 53).

In August 1986, the contaminated test area was divided into the "Controlled Area", 69 villages with ^{137}Cs soil activity density above 555 kBq m^{-2} (15 Ci km^{-2}), and the "Observed Area", the remaining 46 villages of the district. In the same month, the dairy and meat cattle and poultry privately owned by inhabitants of the Controlled Area were compulsorily purchased by state bodies and transferred to public farms. Instead, delivery of milk, meat, and dairy and meat products produced in "clean" territories was organised. Outside the Controlled Area, cattle and poultry were not compulsorily purchased from the population, but processing of milk and meat contaminated above the adopted TPLs was undertaken.

The applied set of countermeasures caused strong alteration of the food rations of the local population (see above), especially with respect to consumption of meat and dairy products and "nature gifts". Due to the change of economic situation in the country after 1992, the countermeasures were gradually weakened.

Agricultural countermeasures

The application of agricultural countermeasures depended on the time elapsed since the accident. In the first period after the accident, when the iodine isotopes were a major hazard, the following measures were recommended:

- Transfer of cattle from pasture to indoor keeping;
- Sorting of agricultural production, where iodine concentrations exceeded the set provisional permissible standards; and
- Processing of agricultural products.

After 3 May, maximum permissible ^{131}I levels in milk were 3,700 Bq L^{-1} for adults and 370 Bq L^{-1} for children. After 6 May, standards were established for water, fish, and leafy vegetables. It was recommended that consumption of berries, mushrooms, and game be stopped.

In the second period (June 1986 to spring 1987), countermeasures were concentrated on the reduction of cesium uptake. The provisional permissible standards of radionuclide concentration in products were introduced on 30 May 1986 (Table 53). In this period the following countermeasures were recommended:

(1) Slaughtering of cattle was forbidden in regions with contamination levels exceeding 555 kBq m^{-2}. It was recommended that cattle be kept on uncontaminated forage at least 1.5 months before slaughtering;

(2) Change of agricultural crop treatment: reduction of operations resulting in dust generation, reduction of the frequency of weeding, and direct harvesting of top parts of the crops;

(3) Restriction on the use of contaminated manure;

(4) Laying-in of dried grass and silage instead of hay; and

(5) Obligatory dosimetric control.

After 1987, the soil has been the main pathway of radionuclide uptake by agricultural production. Agricultural use of arable lands subjected to contamination densities exceeding 1480 kBq m^{-2} was terminated in 1987 to 1988. For the reduction of radionuclide accumulation, large-scale countermeasures were applied in the district. The complex of countermeasures for the agricultural industry, which were applied in the medium- and long-term periods after fallout, may be classified into five groups: organisational, agrotechnical, agrochemical, veterinary and food processing.

Organisational countermeasures principally concern changes in land use. This includes increasing the area of land allocated to crops characterised by low accumulation of radionuclides, and in the case of areas of very high deposition, the abandoning of land for agricultural production. Other changes in land use include substitution for the existing crop with hay, grain, potatoes or grazing animals.

Agrotechnical countermeasures include deep ploughing with turnover of the upper layer (on high fertility soils) and radical or superficial improvement of pastures. The techniques have been placed into two categories: radical and surface improvement. In addition many combinations of ameliorants (lime, organic fertilisers and mineral fertilisers) which can be potentially useful have been evaluated experimentally. It should also be noted that some countermeasures have limitations, for instance, deep ploughing is not applicable for soils with a thin humus layer. Radical improvement of meadows was the main method based on re-ploughing of forage lands and application of lime (on acid soils), mineral and organic fertilisers, as well as sowing of perennial grasses. This is a traditional method for cultivation of forage grass, and it is normally used for all forage land where available. The effectiveness of this option depends on the time elapsed since the deposition. In the first period after deposition, the effectiveness of this option is 2-4 times higher. Radical improvement cannot be implemented in river valleys. The options require a calculation of optimal doses of fertilisers and lime application, taking into account the plant demands for nutrients and acidity of soil. These countermeasures may be effective for several (3-4) years after their application. The data on effectiveness of these countermeasures are shown in Table 54.

Agrochemical countermeasures include liming of acidic soils, application of increased doses of mineral fertilisers, addition of natural sorbents (different kinds of clay minerals), and use of organic fertilisers. The feature of the application of mineral fertilisers to contaminated soils is the modification of the ratio of the main plant nutrients. Liming is also one of the most important countermeasures that has been used to reduce cesium contamination levels in plants. The effectiveness of the main options related to this type of countermeasure is given in Table 55.

Countermeasures involving changes in animal husbandry include a shift from full-time grazing on open pasture to a mixture of pasture grazing and indoor supplementary feeding, use of clean feeds before slaughtering, and use of different forms of ferrocine sorbents (e.g., Prussian blue) to reduce the ^{137}Cs content in animal products. The relevant data on effectiveness of application of Prussian blue in forms typical for the test area are presented in Table 56.

Food processing. The primary objective of countermeasures in Russia after the Chernobyl accident was to produce "clean" agricultural products. However, the processing of milk, meat, cereals and vegetables was also implemented in contaminated districts. As mentioned earlier, general recommendations included processing of milk (especially that exceeding the DILs standard) into cheese, butter and other milk products. Information about the effectiveness of these options is shown in Table 57.

A general summary of the effectiveness of the countermeasures applied is given in Table 58. In the summer of 1988, stricter standards on permissible levels of ^{137}Cs were introduced; these standards were specified in 1991 (Table 54). However, general recommendations for agriculture during that period (1987 to 1996) were analogous to those presented above. Data on the scale of application of agrochemical measures in 1986 to 1989 for the agricultural lands are listed in Table 59. Similar information concerning the application of agrotechnical countermeasures on hay lands and pastures is shown in Table 60.

In assessment of the effectiveness of the countermeasures, the levels of soil contamination with ^{137}Cs relative to isolines 555 kBq m^{-2} and 1480 kBq m^{-2} are of particular practical importance. The 555 kBq m^{-2} contamination level was taken as a threshold for farming and home gardening without obligatory decontamination. The isoline 555 kBq m^{-2} is a boundary of the territory where people were thought to be able to live without imported food products. The 1480 kBq m^{-2} level was taken as a threshold for people to live in the area. In the regions with soil contamination densities of 555 to 1480 kBq m^{-2}, effective countermeasures resulting in a significant reduction of radioactive contamination of home-raised food products were implemented on approximately one-half of the farms.

Practical implementation of countermeasures in the areas with different contamination levels of agricultural lands had its special features.

(1) Areas of up to 185 kBq m^{-2}: No countermeasures were applied.

(2) Areas from 185 to 555 kBq m^{-2}: Agricultural lands were cultivated without any restrictions in accordance with the technologies accepted for this soil-climatic region. Simplified improvement and amelioration of meadows was performed.

(3) Areas from 555 to 1480 kBq m^{-2}: Mineral fertilizers were applied to agricultural lands at a rate of one and one-half or two times the usual dose; lands under potatoes and other vegetables were treated with organic fertilizers. Lime materials were applied to lands with low pH at a rate of one or one and one-half times the usual dose with respect to hydrolytic acidity on cycles of liming. Radical amelioration of hay lands and pastures was conducted. In 1987 to 1988, the pasture lands were

ploughed up. To reduce contamination with ^{137}Cs, beginning in 1988, cattle were fed on clean forage during the last 1.5 to 2 months of fattening.

(4) Areas with ^{137}Cs activity density higher than 1480 kBq m^{-2}: In 1987 about 40% of agricultural lands with this contamination density were taken out of agricultural production. In 1988 all agricultural lands with a contamination density over 1480 kBq m^{-2} were completely taken out of agricultural production.

A feature of agricultural countermeasures in the private sector is that restrictive countermeasures were applied directly after the accident, but application of other countermeasures such as agrochemical and agrotechnical ones were started only in 1990-1991. They consisted mainly in providing private cows with clean feedstuffs. With this purpose, in each settlement the pastures and haylands for private cattle were cultivated, resulting in some cases in a lower ^{137}Cs concentration in the milk of private cows as compared to milk produced in the collective sector. However, the effectiveness of these countermeasures decreased in 1993-1996, and the main method for decreasing the contamination of agricultural products became the application of Prussian blue (see examples given below).

Examples of the effectiveness of agricultural countermeasures application

Restrictive countermeasures. The restrictive countermeasures concerned restriction in consumption of local food products and forest gifts in the area with ^{137}Cs activity density higher than 555 kBq m^{-2}. These settlements can serve as an illustration of restrictive countermeasures properly observed, where up to now the consumption of milk produced in private farms in these settlements does not exceed 15%. The main sources of milk and milk products for inhabitants were shops and markets. Within the last 5-7 years, the number of private cows has increased rapidly in those settlements from which they had been removed. Hence the internal exposure increases in these settlements as well. Nowadays there are two groups of inhabitants in these settlements distinguished by sources of milk. So, a group of inhabitants not consuming private milk is characterised by a lower level of internal dose than the average calculated for the settlements. On the other hand, the level of internal irradiation of the inhabitants consuming private milk exceeds the average level, and this group might be considered as a critical one. In this case, to avoid an increase in internal dose, it might be reasonable to provide private cows with cultivated pastures and haylands, i.e., to apply radical improvement on private haylands.

A good example for evaluation of the main features and factors governing dose formation in settlements under the condition of intensive application of countermeasures is the settlement Shelomy. This settlement was studied carefully in several Russian and international projects. In particular, some important information for the present study was presented in the final report of ECP9 (Strand et al., 1996). It has been shown that, at present, two cohorts of inhabitants may be distinguished in this settlement, taking into account sources of milk consumed. One group, about 10% of the population of Shelomy, consumes private milk, and the other group consumes milk only from state shops. It should be noted that there is a big difference between ^{137}Cs concentrations in private milk and in milk from shops. The average activity of ^{137}Cs in private milk was about 100 Bq L^{-1} while the ^{137}Cs concentration in milk from the shops was about ten times less. Accordingly, internal doses attributed to the consumption of milk varied considerably.

For the first cohort of inhabitants, the internal dose calculated on the basis of data on contamination of private milk and other products derived in the frame of this project was 1.1 mSv a^{-1}, and for the second group, 0.36 mSv a^{-1}. The average internal dose calculated for inhabitants of the settlement in 1991-1995 amounted to 0.445 mSv a^{-1}, which is in good agreement with doses calculated from whole body measurements (0.42 mSv a^{-1}). This allows the estimation of the effect of removal of private cows as the difference between doses calculated for the cohort of inhabitants consuming private milk and doses calculated for each year on the basis of data on whole body measurements. On the whole, these results allow a conclusion that the annual averted dose in 1991-1995 was about 0.6 mSv a^{-1}.

The contributions of agricultural products to internal dose varied for different cohorts of inhabitants of this settlement (Table 61). In the existing situation the main dose-forming products are mushrooms. The contribution of external dose to the irradiation of inhabitants is rather high (1.15 mSv a^{-1}). The total dose for inhabitants of the settlement is above 1 mSv a^{-1}, which requires countermeasure application. Besides, there is a tendency toward an increase in the number of private cows, which will result in an increase in internal dose to the population.

Improvement of fodder lands. In the example shown in Figure 5, until 1991 all the private cows used unimproved pastures, thus resulting in a high level of milk contamination and, due to that, high internal doses to the population. In 1992, when the pastures had been radically improved, they were allocated to private cows, and the milk contamination decreased sharply; it became lower than that of collective milk, thereby illustrating the high efficiency of this countermeasure. Figure 5 also demonstrates that in 1992-1995, a certain increase in ^{137}Cs concentration in the milk of private cows was detected due to the reduced efficiency of radical improvement within this period of time. However, this example illustrates a rather high efficiency for this countermeasure, which was widely applied on the territory of Russia subjected to contamination after the Chernobyl accident.

Application of ^{137}Cs binders. In 1993-1996, ^{137}Cs binders were widely used in many settlements in the form of bifege or boli. Fig. 6 illustrates the dynamics of population internal doses (based on whole body measurements) in the settlement of Smyalch and the dynamics of the efficiency of the increase in the binder doses per cow. The figure shows that its application allowed the population exposure doses to be decreased significantly (by a factor of 2).

Forest countermeasures

For implementation of countermeasures, the forests of the Novozybkov district were divided into 3 zones: A, B and C, corresponding to different levels of ^{137}Cs deposition. Forests with a level of deposits above 1480 kBq m^{-2} (zone A) were completely excluded from economic use. These forests were permitted only measures to preserve their quality, prevent fires, and control dispersion of pests and diseases. Public access to these forests and collection of forest products (mushrooms, berries, etc.) was prohibited.

These restrictions were also applied to forests of zone B, with levels of ^{137}Cs deposition between 555 and 1480 kBq m^{-2}. The main forestry task in this case was to maintain the ecological role of the forest. Timber production was partially suspended in these forest stands until special technologies, machines and mechanisms could be developed to ensure occupational radiation safety and to obtain timber with contamination below the adopted Intervention Limits. Any usage of forest products (mushrooms, berries, medical herbs, etc.) was also prohibited, and this prohibition continues till the present time.

Restrictions on the gathering of berries and mushrooms were also imposed in forests belonging to group C, with levels of ^{137}Cs deposition between 185 and 555 kBq m^{-2}. However, unlike the previous classes, sanitary felling and production of industrial timber were permitted. Artificial forest restorations were not allowed. Harvesting of trees to produce industrial timber is carried out on the basis of radiological survey results to guarantee that external dose rates and contamination of wood have minimal values.

Within zones C and B there are also small areas with densities of ^{137}Cs deposition below 185 kBq m^{-2}. Forestry without restriction and use of forest fodder for animals (including grazing of milk cows on forest clearings and collection of firewood in the forest) are allowed in these forests. However, gathering of berries and mushrooms is allowed only in forests with levels of ^{137}Cs deposition less than 74 kBq per m^{-2}.

The measures described for forests are mainly of a restrictive character and were intended to decrease exposure of the population, taking into account the main dose-forming pathways. However, these countermeasures were observed by the rural population only until 1990. Since 1990, gathering of mushrooms and berries by the local population has been (illegally) re-established on the whole territory except for areas of wood production, which are under the official control of the local forest authorities.

Countermeasures against external irradiation applied in contaminated settlements

In the summer of 1989, the nine most contaminated settlements of the test area were decontaminated. This procedure included removal of the upper layer of virgin soil from squares, streets, sports and rest grounds, and grounds around production targets and dwellings; covering cleaned and contaminated plots with clean soil and sand; and covering of streets and yards with asphalt. Kindergartens and schools, as well as strips 10-15 meters wide around them, were carefully decontaminated. Some village parts and their surroundings (kitchen gardens, fruit gardens, arable land) were not decontaminated. The effectiveness of decontamination was estimated from the measurements of dose rates in different locations before and after decontamination. The observed decrease of the dose rate varied between a factor of 1.1-1.5 for houses to a factor of 1.5-5 for streets and yards. The measurements performed during the following years showed that the decontamination effect persisted in time.

Table 62 presents the average efficiency of decrease of the annual external dose in different population groups in three large villages after decontamination, determined by calculations and confirmed by individual TLD measurements of the dose to inhabitants.

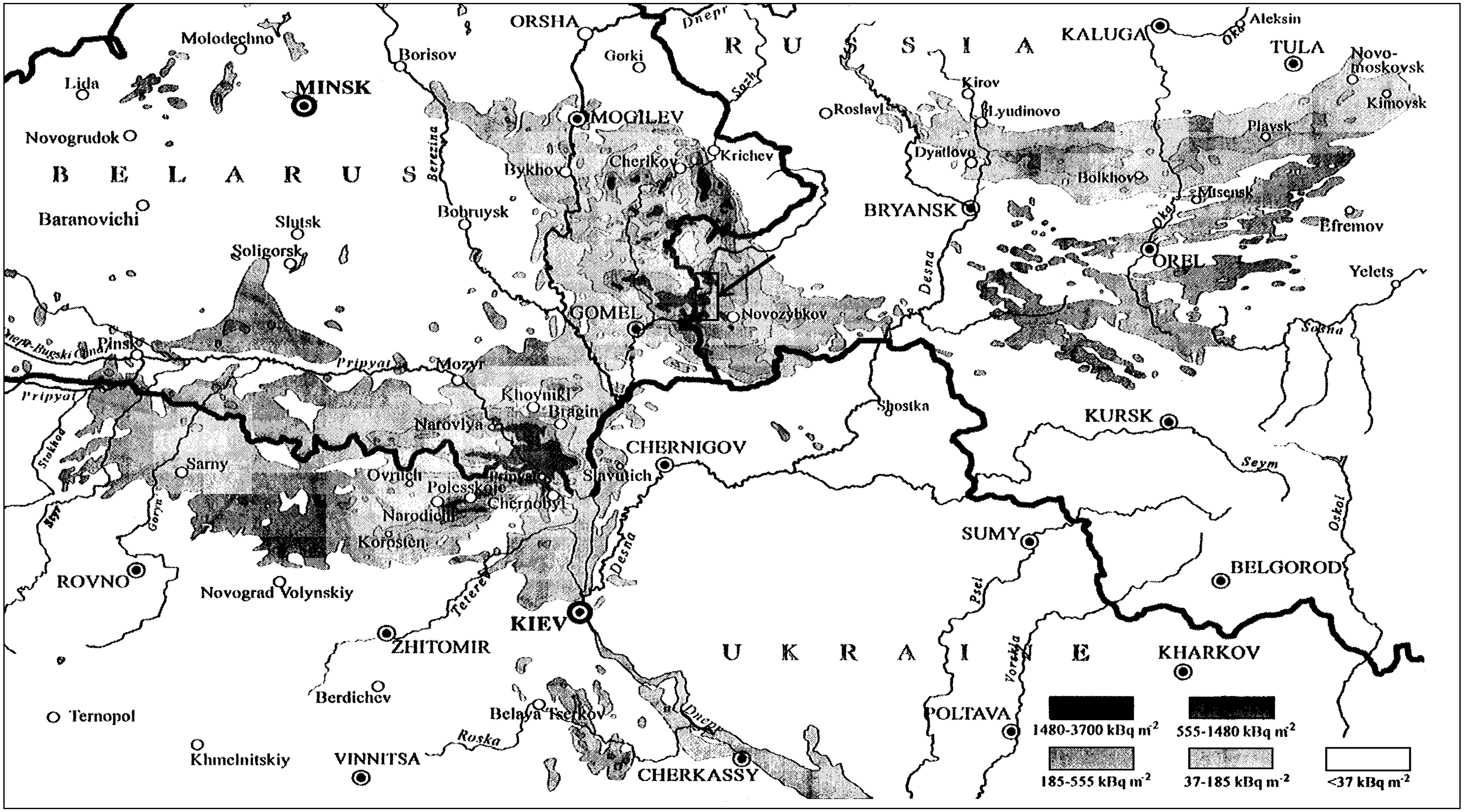

Fig. 1. The regions of Russia, Belarus and Ukraine contaminated with Cs-137 as a result of the Chernobyl accident. The Iput test area (near center of map) is indicated by an arrow.

Fig. 2. Position of the test region on the map of Russia.

Fig. 3. Scheme of the Iput River, showing the area considered in the test scenario.

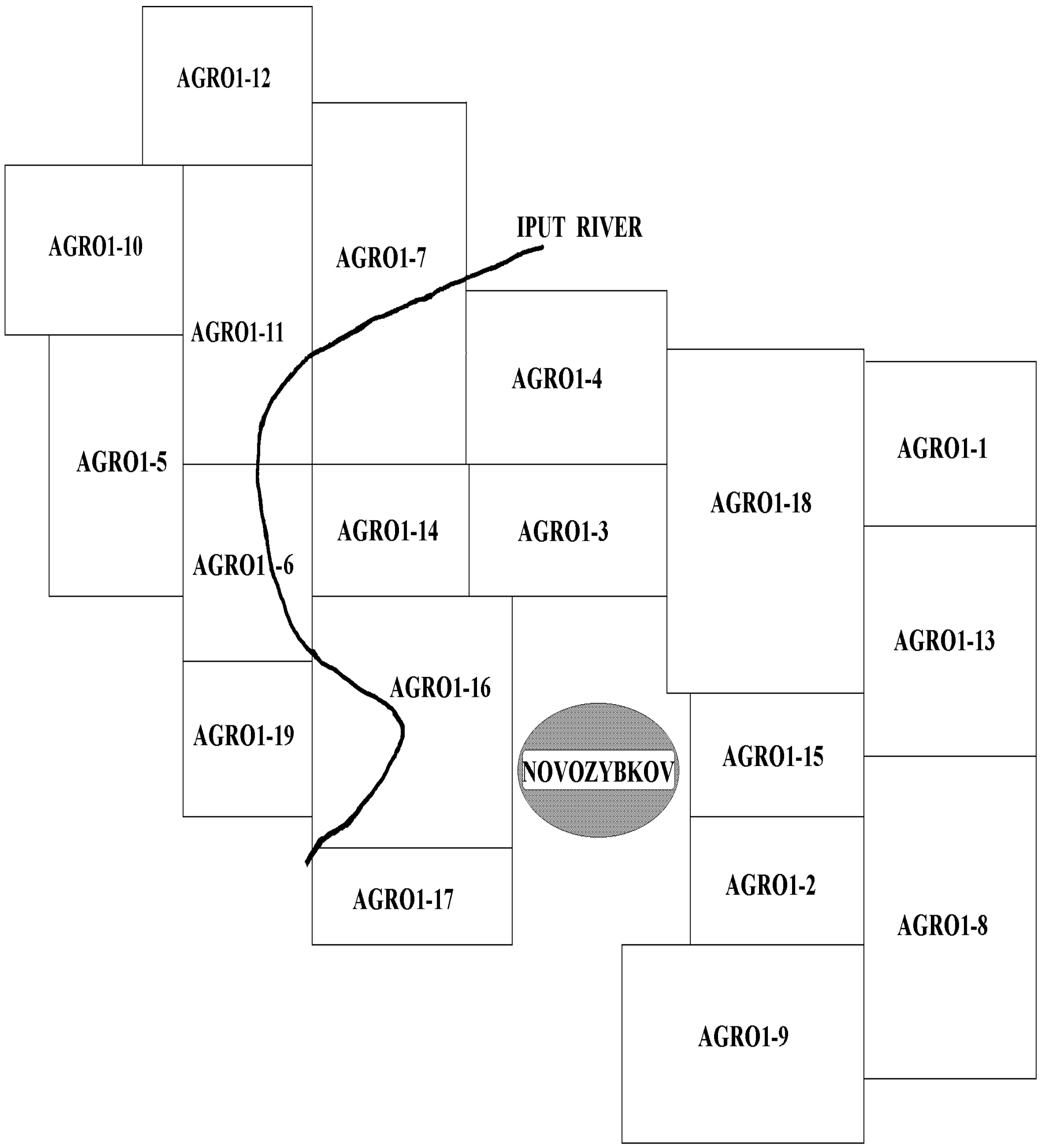

Fig. 4. Scheme of agricultural subareas in the test region.

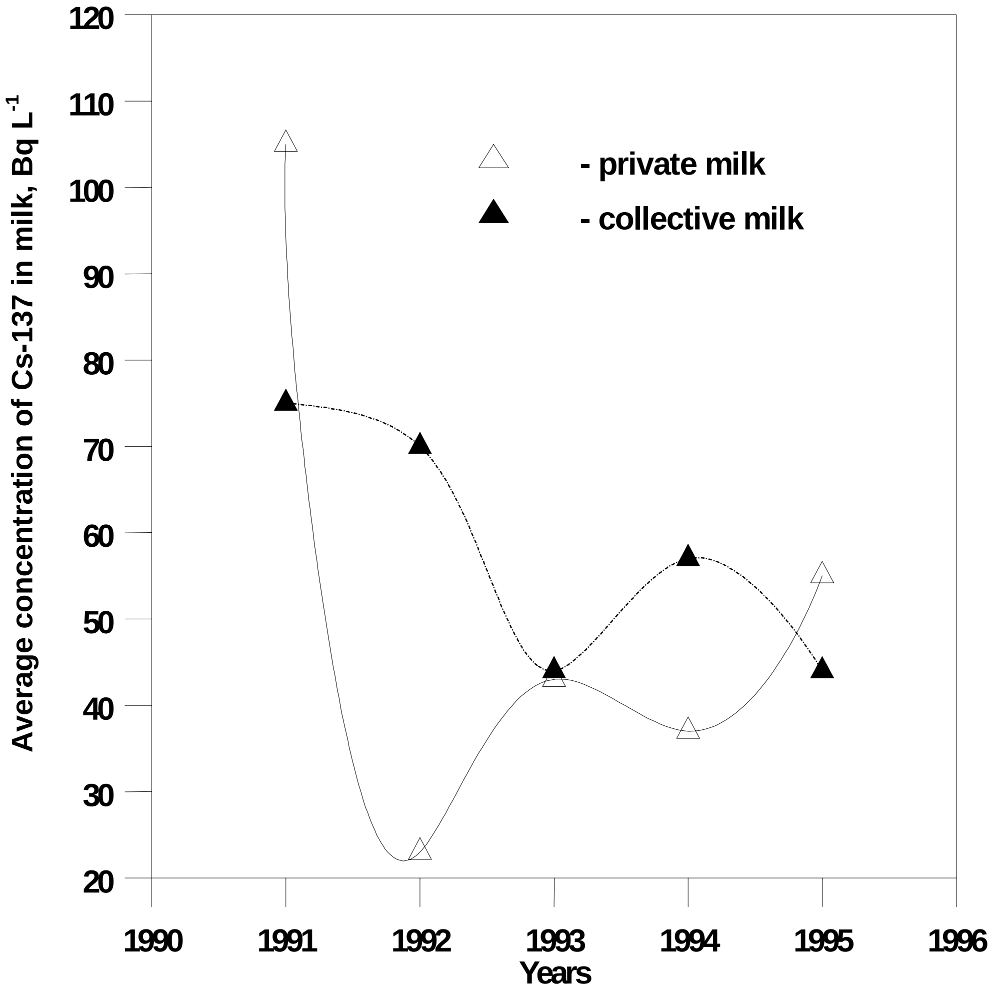

Fig. 5. Dynamics of the ^{137}Cs specific activity in milk of private and collectively owned cows (settlement Pobozheyevka).

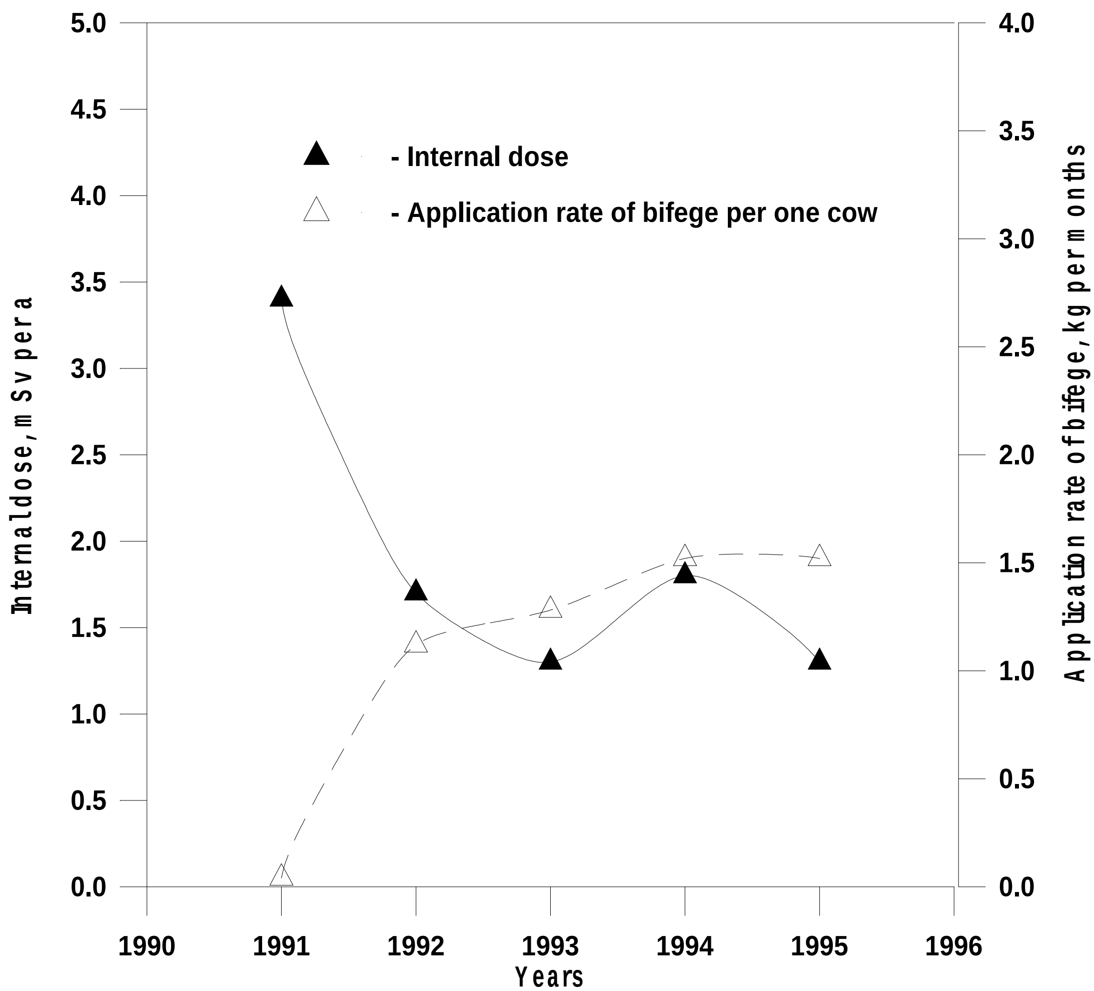

Fig. 6. Internal doses and dynamics of the application rate of bifege per cow in Smyalch settlement. The total number of private milk cows in the settlement in the period under consideration was about one hundred.

Table 1. Assessments of the ^{137}Cs concentrations in ground-level air of the test area, 1986 (Novozybkov district).

Time	Concentration, mBq m^{-3}
28.04-30.04.86	60000 ± 40000
1.05-10.05.86	2000 ± 1200
11.05-20.05.86	400 ± 200
21.05-31.05.86	200 ± 100
1.06-30.06.86	80 ± 40

Table 2. Relative content of radionuclides in the soil of the test area (30 May 1986).

Radionuclide	Relative content, %
^{89}Sr	2.7 ± 1.6
^{90}Sr	0.5 ± 0.3
^{95}Zr	1.2 ± 0.5
^{95}Nb	1.5 ± 0.5
^{103}Ru	24.0 ± 4.8
^{106}Ru	9.0 ± 5.2
^{131}I	12.2 ± 4.8
^{134}Cs	13.4 ± 4.0
^{137}Cs	25.3 ± 8.0
^{140}Ba	3.5 ± 0.9
^{140}La	3.7 ± 1.1
^{141}Ce	1.8 ± 0.6
^{144}Ce	1.2 ± 0.7

Table 3. Density of ^{137}Cs contamination with and composition of the population in the settlements of Novozybkov district (1 October 1991).

Subarea	Number of samples	Density of contamination with ^{137}Cs, kBq m^{-2}			Composition of population		
		Min.	Ave.	Max.	Total	Male	Female
AGRO1-1	143	140	380	1380	778	324	454
AGRO1-2	36	40	460	660	857	382	475
AGRO1-3	95	110	610	1890	785	346	439
AGRO1-4	118	260	730	1470	776	322	454
AGRO1-5	124	320	980	2290	874	381	493
AGRO1-6	112	290	860	2160	1316	567	749
AGRO1-7	73	170	700	1310	899	384	515
AGRO1-8	49	70	280	470	995	441	554
AGRO1-9	95	130	530	940	990	420	570
AGRO1-10	34	190	1700	2670	681	275	406
AGRO1-11	85	460	900	1750	985	419	566
AGRO1-12	107	160	600	1140	1435	617	818
AGRO1-13	51	125	310	550	769	323	446
AGRO1-14	50	100	700	1200	746	325	421
AGRO1-15	75	55	470	1030	1666	747	919
AGRO1-16	118	150	1020	1560	622	249	373
AGRO1-17	165	155	920	2460	1102	485	617
AGRO1-18	24	110	420	620	432	181	251
AGRO1-19	53	300	910	1400	144	61	83

Table 4. Vertical distribution of ^{137}Cs in Novozybkov area soils (1 August, 1990).

Layer (cm)	^{137}Cs, kBq kg^{-1}	^{137}Cs, kBq m^{-2}	%
	A. Uncultivated soils, fields		
0 - 2.5	30	726	82
2.5-5.0	2.0	75	8.5
5 –10	0.64	62	7
10-15	0.25	22	2.5
0 -15	-	885	-
	B. Cultivated soils, kitchen-gardens		
0 – 5	3.0	187	33
5 -10	2.8	214	38
10-15	1.9	138	24
15-20	0.4	26	4.6
20-30	0.02	2	<1
0-30	-	567	-
	C. Forest soils		
0 -2.5	57	1022	92
2.5-5.0	1.3	54	5
5 -10	0.4	24	2
10-15	0.15	15	1
0-15	-	1115	-

Table 5. Distribution of ^{137}Cs activity on soil particles of different size in 1987.

Region	Size of soil fractions, mm					
	<0.05	0.05-0.1	0.1-0.25	0.25-0.5	0.5-1.0	>1.0
Novozybkov district, Bryansk Region	52-55	-	22-30	6-7	3-4	8-10
Chernobyl area	15-20	8	20-30	22-24	19-22	7-12

Table 6. Section-averaged concentrations of ^{137}Cs in the river water during a flooding period (9 April - 15 April, 1991).

Hydrometric post	Distance from Iput river source, km	Concentration of ^{137}Cs, mBq L^{-1}	
		Solution	Suspension
1	170	3.0 ± 1.1	1.1 ± 0.2
2	230	3.3 ± 1.1	<0.1
3	254	21.1 ± 0.7	1.1 ± 0.1
4	264	14 ± 7	6.3 ± 1.8
5	304	170 ± 30	4.4 ± 0.4
6	330	166 ± 26	7.8 ± 0.7
7	363	366 ± 40	17 ± 10

Table 7. Section-averaged concentrations of ^{137}Cs in the river water during a low-water period (27 July - 9 August, 1991).

Hydrometric posts	Concentration of ^{137}Cs, mBq L^{-1}	
	Solution	Suspension
1	1.5	<0.1
2	2.6	1.1
3	3.0	<0.1
4	44	3
5	94	11
6	151	12
7	257	20

Note: The average uncertainty is 20% (95% confidence interval).

Table 8. Average concentrations of ^{137}Cs in the lake water (1991).

Sample	Solution	Suspension
^{137}Cs, Bq L^{-1}	14 ± 6	0.4 ± 0.3

Table 9. Contamination density, vertical distribution, and specific activity of ^{137}Cs in the upper 20-cm soil layer of the flood plain of the Iput River near hydrometric posts Nos.1-7 (15 April 1991).

Settlement	Layer depth, cm	Contamination density ^{137}Cs, kBq m^{-2}	Specific activity of soil, Bq kg^{-1}
Krytoiar (near hydrometric post No. 1)	0-2	1.1	43
	3-4	2.0	58
	5-6	2.4	68
	7-7	2.7	65
	9-10	0.7	17
	11-15	0.5	5
	16-20	0.7	9
Belovodka (near H. post No. 2)	0-2	0.7	21
	3-4	0.4	11
	5-6	0.4	9
	7-8	0.6	14
	9-10	0.4	10
	11-15	0.6	7
	16-20	<0.1	<0.4
Kazarichi (near H. post No. 3)	0-2	8.5	370
	3-4	25	750
	5-6	33	910
	7-8	2.2	56
	9-10	0.5	12
	11-15	0.4	4
	16-20	<0.1	<0.4
Tvorishino (near H. post No. 4)	0-2	15	670
	3-4	8.1	220
	5-6	5.9	140
	7-8	13.0	315
	9-10	52	1385
	11-15	43	530
	16-20	2.2	25

Table 9. (continued)

Settlement	Layer depth, cm	Contamination density ^{137}Cs, kBq m^{-2}	Specific activity of soil, Bq kg^{-1}
Usherpie (near H. post No. 5)	0-2	20	950
	3-4	23	940
	5-6	28	1025
	7-8	34	780
	9-10	26	620
	11-15	2.6	32
	16-20	1.8	20
Settlement	Layer depth, cm	Contamination density ^{137}Cs, kBq m^{-2}	Specific activity of soil, Bq kg^{-1}
Starue Bobovichi (near H. post No.6)	0-2	82	2270
	3-4	90	2550
	5-6	82	2440
	7-8	94	2750
	9-10	317	7960
	11-15	131	1200
	16-20	0.7	10
Vyskov (near H. post No. 7)	0-2	84	5340
	3-4	585	21090
	5-6	1260	34040
	7-8	200	5620
	9-10	33	890
	11-15	42	630
	16-20	18	250

Note: The average uncertainty is 20% (95% confidence interval).

Table 10. ^{137}Cs content in bottom sediments (Iput river, summer 1991).

Hydrometric posts	Layer depth, cm	Contamination density with ^{137}Cs, kBq m^{-2}	Specific activity of bottom sediments, Bq kg^{-1}
4	0-2	3.7	118
	3-4	4.2	96
	5-6	5.8	122
	7-8	4.0	81
	9-10	0.5	10
	11-15	<0.1	<0.6
5	0-2	4.4	130
	3-4	5.3	150
	5-6	5.4	115
	7-8	0.6	12
	9-10	0.5	12
	11-15	<0.1	<0.4
6	0-2	76	2720
	3-4	83	2430
	5-6	98	2180
	7-8	18	420
	9-10	0.7	16
	11-15	0.3	2.6

Note: The average uncertainty is 20% (95% confidence interval).

Table 11. Characteristics of the Iput watershed contaminated with ^{137}Cs.

Hydrometric post	Local watershed		Total watershed (cumulative)	
	Watershed area, km^2	Activity stored in watershed, TBq	Watershed area, km^2	Activity stored in watershed, TBq
1. (Krytojar)	4020	34	4020	34
2. (Belovodka)	1340	13	5360	47
3. (Kazarichi)	510	16	5860	64
4. (Tvorishino)	180	58	6040	122
5. (Usherpie)	2280	483	8320	604
6. (St. Bobovichi)	855	660	9170	1265
7. (Vishkov)	440	410	9610	1676

Table 12. Average annual activity of ^{137}Cs in water (Bq L^{-1}) of the Iput river (hydrometric post in Dobrush, Belorussia, near the inflow of the Iput river into the Sozh river).

Year	1987	1988	1989	1990	1991
Iput, near Dobrush	2.0	1.4	0.60	0.55	0.23

Table 13. Daily rainfall observation (April-May, 1986).

Code of rainfall measuring station	Year	Month	Day	Daily precipitation, mm
26898	1986	04	20	13.1
26898	1986	04	21	no rain
26898	1986	04	22	no rain
26898	1986	04	23	no rain
26898	1986	04	24	no rain
26898	1986	04	25	no rain
26898	1986	04	26	no rain
26898	1986	04	27	no rain
26898	1986	04	28	no rain
26898	1986	04	29	no rain
26898	1986	04	30	no rain
26898	1986	05	1	no rain
26898	1986	05	2	no rain
26898	1986	05	3	no rain
26898	1986	05	4	no rain
26898	1986	05	5	no rain
26898	1986	05	6	no rain
26898	1986	05	7	no rain
26898	1986	05	8	no rain
26898	1986	05	9	no rain
26898	1986	05	10	no rain
26898	1986	05	11	no rain
26898	1986	05	12	no rain
26898	1986	05	13	no rain
26898	1986	05	14	no rain
26898	1986	05	15	no rain
33042	1986	04	20	4.7
33042	1986	05	20	2.3
26882	1986	04	20	8.9
26882	1986	05	02	0.6
26882	1986	05	11	0.5
26882	1986	05	12	0.8
26882	1986	05	17	0.9
26882	1986	05	18	2.2
26882	1986	05	20	0.6
26882	1986	05	21	5.6

Table 13. (continued)

Code of rainfall measuring station	Year	Month	Day	Daily precipitation, mm
26976	1986	04	20	19.4
26976	1986	04	26	0.1
26976	1986	04	28	1.6
26976	1986	04	30	0.6
26976	1986	05	2	0.8
26976	1986	05	11	3.2
26976	1986	05	12	10.8
26976	1986	05	13	2.6
26976	1986	05	18	1.9
26976	1986	05	20	5.4
26976	1986	05	21	2.1
26974	1986	04	20	6.6
26974	1986	04	28	11.9
26974	1986	04	29	0.4
26974	1986	04	09	1.7
26974	1986	05	11	7.2
26974	1986	05	12	1.2
26974	1986	05	13	3.3
26974	1986	05	18	2.8
26974	1986	05	20	4.5

Table 14. Hydrographic characteristics of the Iput river.

Hydrometric post, No.	River width, m	River depth, m	Flow rate, m s^{-1}	River plain width, km
1	20-40	1.5-3.0	0.1-0.4	0.2-0.5 (max=2)
2-4	10-96	0.7-3.0	0.2-0.3	5.0
5	60	4	0.2	1-6
6-7	30-68	1.2-3.0	0.2	-

Table 15. Annual average characteristics of water and sediment discharge for the Iput River.

Characteristic distribution	Average discharge	Cumulative frequency of the annual discharge, %					
		1	5	10	25	50	74
Annual							
Water discharge, $m^3 s^{-1}$	42.8	81.3	68.4	60.0	48.8	37.2	28.6
Sediment discharge, 10^3 tonnes a^{-1}	11	37	26	22	14	9.0	5.6
Over a flooding event							
Water discharge, $m^3 s^{-1}$	87.4	508	200	183	173	73.4	45.4
Sediment discharge, 10^3 tonnes a^{-1}	7.6	38	23	17	9.9	4.7	2.5

Table 16. Components of water balance of the Iput river.

Components of water balance, mm	Value
Precipitation	730
River flow:	
total	173
surface	131
underground	42
Evaporation	557
Infiltration	599
Runoff coefficient	0.24
Infiltration coefficient	0.82

Table 17. Month-to-month distribution of discharges of water and suspended matter to the Iput river.

Month	Average water discharge, $m^3\ s^{-1}$	Suspended matter discharge, $kg\ s^{-1}$
January	20	0.13
February	15	0.097
March	38	0.45
April	230	2.3
May	73	0.41
June	20	0.17
July	14	0.12
August	14	0.099
September	19	0.079
October	22	0.086
November	26	0.13
December	23	0.13

Table 18. Range of monthly air temperatures in the test area (long-term observations).

Month	Temperature (^oC)		
	Min	Average	Max
January	-40	-7	+5
February	-37	-6	+7
March	-32	0	+21
April	-18	+7	+30
May	-7	+12	+34
June	-2	+13	+36
July	-2	+15	+37
August	-2	+15	+32
September	-12	+13	+30
October	-26	0	+21
November	-35	-3	+12
December	-40	-7	+5

Table 19. Range of surface water temperatures in lakes of the test area (long-term observations).

Month	Temperature (^{o} C)
April	5.0-15.0
May	13.3-15.2
June	17.2-18.7
July	18.6-22.5
August	19.4-22.0
September	13.6-16.8
October	7.2-9.2

Table 20. Characteristics of the forests in the territory of the Iput test area.

Forest Unit	Area, km^{-2}	Contamination, kBq m^{-2} Average	St. Err.	Type of forest	Number of inhabitants
1	13.6	1100	220	Deciduous, 56%	1535
2	19.8	870	150	Deciduous, 66%	1950
3	17.2	1900	640	Coniferous, 52%	1508
4	3.5	1500	340	Coniferous, 60%	1420
5	15	910	100	Coniferous, 91%	1716
6	24.5	520	100	Coniferous, 90%	1074
7	3	780	170	Deciduous, 68%	863
8	8.5	620	120	Coniferous, 81%	296
9	6.7	460	40	Coniferous, 66%	682
10	8.8	360	80	Deciduous, 85%	1031
11	13	1500	330	Coniferous, 77%	134
12	28.9	1500	410	Coniferous, 81%	919
13	6.8	810	130	Coniferous, 92%	85
14	48.6	750	190	Coniferous, 67%	1183
15	11.4	910	100	Coniferous, 58%	985

Table 21. Potential yield of mushrooms in the territory of the Iput test area, kg a^{-1}.

Forest unit	*Boletus edulis*	*Cantharellus cibarius*	*Suillus luteus*	*Russula cyanoxantha*	*Lactarius necator*	*Tricholoma flavovirens*	*Xerocomus badius*
1	5651	4011	12183	4011	2546	4751	5671
2	8227	5839	17737	5839	3707	6917	8257
3	7147	5072	15408	5072	3220	6009	7172
4	1454	1032	3135	1032	655	1223	1460
5	6233	4424	13437	4424	2808	5240	6255
6	10180	7225	21947	7225	4586	8559	10217
7	1247	885	2687	885	562	1048	1251
8	3532	2507	7614	2507	1591	2969	3545
9	2784	1976	6002	1976	1254	2341	2794
10	3656	2595	7883	2595	1647	3074	3670
11	5402	3834	11645	3834	2434	4542	5421
12	12008	8523	25889	8523	5410	10096	12051
13	2825	2005	6091	2005	1273	2376	2836
14	20193	14332	43536	14332	9098	16978	20266
15	4737	3362	10212	3362	2134	3983	4754

Table 22. Potential yield of berries in the territory of the Iput test area, kg a^{-1}.

Forest unit	*Vaccinium myrtillus*	*Rubus idaeus*	*Fragaria vesca*
1	9067	3022	1511
2	13200	4400	2200
3	11467	3822	1911
4	2333	778	389
5	10000	3333	1667
6	16333	5444	2722
7	2000	667	333
8	5667	1889	944
9	4467	1489	744
10	5867	1956	978
11	8667	2889	1444
12	19267	6422	3211
13	4533	1511	756
14	32400	10800	5400
15	7600	2533	1267

Table 23. General characteristics of the test area (1989).

Number of populated sites	103
Number of farms (subareas)	19
Distribution of farms according to contamination with ^{137}Cs, kBq m^{-2}:	
< 555 kBq m^{-2}	6
555 - 1480 kBq m^{-2}	9
1480 - 2960 kBq m^{-2}	4

Table 24. Structure of land use in the test area (AGRO1).

Agricultural lands	Area, km^2	Area, %
Plough lands	386	64.3
Long-term plantings and gardens	5	0.8
Hay lands	100	16.7
Pastures	109	18.2
Total agricultural area, km^2	600	100

Table 25. List of collective farms (subareas) situated on the test area.

Agricultural subarea	Main settlement (Name of farm)
AGRO1-1	Manyuki ("Vperiod")
AGRO1-2	Trostan ("Voskhod")
AGRO1-3	Vnukovitchyi ("Imeni Kirova")
AGRO1-4	Chaleevitchyi ("Kommunar")
AGRO1-5	Staryi Vischkov ("Komsomolets")
AGRO1-6	Stariye Bobovitchi ("Krasnya Put")
AGRO1-7	Katitchyi ("Imeni Lenina")
AGRO1-8	Staryi Kryivetc ("Novaya Zhizn")
AGRO1-9	Snovskoye ("Pamyati Lenina")
AGRO1-10	Svyatsk ("Imeni XXII Partsyezda")
AGRO1-11	Noviye Bobovitchi ("Reshitelny")
AGRO1-12	Verestchakyi ("Rossiya")
AGRO1-13	Kataschin ("Udarnik")
AGRO1-14	Schelomi ("Rodina")
AGRO1-15	Zamischevo ("Boyevik")
AGRO1-16	Novoye Mesto ("Volna Revolyutsii)
AGRO1-17	Dyemenka ("NBIFASS")
AGRO1-18	Krutoberyozka ("Krutoberyozka")
AGRO1-19	Perevoz ("Novozybkovsky")

Table 26. Land use on farms (subareas) of the test area, km^2.

Agricultural subareas	Total area of agricultural lands, km^2	Plough land, km^2	Hay lands and pastures, km^2
AGRO 1-1	25	20	5
AGRO 1-2	23	17	6
AGRO 1-3	30	22	8
AGRO 1-4	28	19	9
AGRO 1-5	30	16	14
AGRO 1-6	25	13	12
AGRO 1-7	41	21	20
AGRO 1-8	54	41	13
AGRO 1-9	46	31	15
AGRO 1-10	21	12	9
AGRO 1-11	45	25	20
AGRO 1-12	48	27	21
AGRO 1-13	27	22	5
AGRO 1-14	23	16	7
AGRO 1-15	21	16	5
AGRO 1-16	43	28	15
AGRO 1-17	6	4	2
AGRO 1-18	28	24	4
AGRO 1-19	34	21	13

Table 27. Distribution of agricultural lands in the test area by soil types, %.

Soil	Distribution, %
Soddy-podzolic	93.2
Soddy-podzolic gley	2.2
Peaty-swamped	0.4
Flooded	4.2

Table 28. Agrochemical characteristics of major soil types in the test area.

Soil	Mechanical composition	pH	Humus, %	P	K	Ca	Mg	Total exchange bases
				mg per 100 g soil				mg-eq. per100 g soil
Soddy-podzolic	Sandy	5.4	1.3	2.2	7.4	3.2	1.8	5.5
Soddy-podzolic	Sandy loam	5.3	3.3	3.3	9.4	3.8	1.8	5.6
Soddy-podzolic	Light sandy loam	4.8	1.7	4.9	1.6	4.6	1.8	7.6
Soddy-podzolic	Light sandy loam	6.5	5.0	17.2	15.6	7.6	0.8	-
Soddy	Inter-mediate loam	6.8	4.8	2.5	16.4	10.9	1.5	12.4
Swamp-gley	Inter-mediate loam	4.5	7.5	1.5	17.8	15.6	3.3	18.9
Light-grey forest	Inter-mediate loam	5.6	2.1	12.4	10.7	5.8	1.1	-
Grey forest	Light loam	4.9	2.1	30.6	36.1	10.1	1.3	14.7
Grey forest	Inter-mediate	6.9	4.4	33.3	30.1	21.7	1.3	23.8

Table 29. Proportions of different soil types by agricultural subareas (%).

Agricultural subarea	Soil types				
	soddy-podzolic		soddy-podzolic gley (sandy loam)	peaty swamped	flooded
	sandy	sandy loam			
AGRO1-1	39.7	46.1	7.6	5.5	1.1
AGRO1-2	38.7	54.3	1.0	-	6.0
AGRO1-3	49.9	29.7	5.0	2.8	12.5
AGRO1-4	11.6	66.0	-	12.5	9.9
AGRO1-5	6.0	74.2	-	19.1	0.7
AGRO1-6	59.9	21.0	-	2.1	17.0
AGRO1-7	6.1	52.3	-	24.0	16.7
AGRO1-8	2.3	71.8	10.9	3.1	11.9
AGRO1-9	58.9	26.8	4.7	1.5	8.1
AGRO1-10	8.0	72.7	-	12.4	6.9
AGRO1-11	13.6	73.9	-	8.4	4.1
AGRO1-12	32.6	44.7	-	22.7	-
AGRO1-13	-	94.8	1.2	-	4.0
AGRO1-14	9.3	73.2	-	17.5	-
AGRO1-15	-	88.9	-	11.1	-
AGRO1-16	49.3	30.0	-	2.9	17.8
AGRO1-17	26.9	56.3	-	6.4	10.4
AGRO1-18	53.7	40.3	1.0	2.4	2.6
AGRO1-19	54.3	41.0	-	1.7	3.0

Table 30. Average acidity of different soils by agricultural subareas.

Agricultural subareas	Soils	pH	
		ploughed layer	subsoil
AGRO1-1	Soddy-podzolic sandy	4.8	4.6
	soddy-podzolic sandy loam	5.2	4.8
	soddy-podzolic gley sandy loam	5.3	5.6
	peaty swamped	4.2	4.2
	flooded	5.3	5.8
AGRO1-2	soddy-podzolic sandy loam	5.2	5.5
	soddy-podzolic gley sandy loam	5.3	5.4
	flooded	5.2	5.2
AGRO1-3	soddy-podzolic sandy	5.3	5.3
	soddy-podzolic gley sandy loam	5.4	5.4
	peaty swamped	5.8	4.8
	flooded	6.2	7.0
AGRO1-4	soddy-podzolic sandy	5.5	4.9
	soddy-podzolic sandy loam	4.9	5.4
AGRO1-5	soddy-podzolic sandy loam	5.2	6.0
	peaty swamped	5.3	5.5
	flooded	5.2	5.2
AGRO1-6	soddy-podzolic sandy	4.6	4.6
	flooded	5.4	5.6
AGRO1-7	soddy-podzolic sandy loam	5.2	5.3
AGRO1-8	soddy-podzolic sandy loam	4.7	5.1
	peaty swamped	5.4	6.0
	flooded	5.4	5.0
AGRO1-9	soddy-podzolic sandy	4.5	4.3
	soddy-podzolic sandy loam	5.5	5.3
	soddy-podzolic gley sandy	4.4	4.4
	soddy-podzolic gley sandy loam	4.4	4.4
AGRO1-10	soddy-podzolic sandy loam	5.0	5.1
	peaty swamped	5.6	5.6
	flooded	6.2	6.2
AGRO1-11	soddy-podzolic sandy	5.0	4.8
	soddy-podzolic sandy loam	5.2	5.2
	peaty swamped	5.0	5.5
	flooded	4.8	4.8
AGRO1-12	soddy-podzolic sandy	4.9	4.9
	soddy-podzolic sandy loam	5.0	5.7
	peaty swamped	5.7	6.1
AGRO1-13	soddy-podzolic sandy loam	5.2	5.2
	soddy-podzolic light loam	5.4	4.8
	soddy-podzolic gley sandy loam	5.3	5.4
	flooded	4.6	4.6

Table 30. (continued)

Agricultural subareas	Soils	pH	
		ploughed layer	subsoil
AGRO1-14	soddy-podzolic sandy soddy-podzolic sandy loam peaty swamped	4.6 4.8 5.2	4.6 4.7 5.6
AGRO1-15	soddy-podzolic sandy loam flooded	5.2 4.8	5.3 4.9
AGRO1-16	soddy-podzolic sandy soddy-podzolic sandy loam peaty swamped flooded	5.5 5.2 5.2 4.6	5.1 5.4 5.8 4.6
AGRO1-17	soddy-podzolic sandy loam soddy-podzolic sandy loam soddy-podzolic gley sandy loam flooded	4.8 5.6 5.3 4.8	4.8 4.7 4.6 5.4
AGRO1-18	soddy-podzolic sandy soddy-podzolic sandy loam peaty swamped flooded	4.9 4.6 4.6 5.8	4.8 4.8 4.6 5.6
AGRO1-19	Soddy-podzolic sandy Soddy-podzolic sandy loam peaty swamped Flooded	5.1 4.9 5.2 5.0	4.9 5.2 5.4 5.3

Table 31. Time of sowing and harvesting of crops.

Crop type	Dates of sowing	Dates of harvesting
Winter rye	20.08 - 10.09	20.07 - 05.09
Winter wheat	20.08 - 10.09	20.07 - 05.09
Spring barley	15.04 - 05.05	20.08 - 30.08
Maize (for silage)	10.05 - 30.05	01.09 - 15.09
Potato	01.05 - 10.05	20.09 - 10.10
Root crops	20.04 - 10.05	20.09 - 30.09
Cabbage	15.05 - 30.05	20.08 - 30.08 (early) 20.09 - 30.09 (late)
Vegetables	20.05 - 30.05	20.07 - 10.08
Grasses	10.04 - 20.04	1 term 10.06 - 20.06 2 term 20.07 - 30.07 3 term 10.09 - 20.09

Table 32. Yields of grass stand and silage in the test area, 1986.

Type	Yield (kg m^{-2})
Hay: perennial grasses (dry weight)	0.308
Natural grasses (dry weight)	0.136
Silage (fresh weight)	4.05

Table 33. Keeping of animals.

Pasture period	Start - 1 May -10 May End - 10 Oct.- 20 Oct. Average duration is 170-180 days
Stable period	Duration of stable period may range from 146 to 200 days

Table 34. Annual ration for bull calves at a farm in the test area, kg a^{-1}.

Components of ration	Amount, kg a^{-1}
Green	2724
Hay	532
Silage*	3163
Root crops	146
Potato	125
Pasture	-
Concentrates **	815

* The main component of silage is green-cut maize, content of dry matter is 20%.

**Concentrates include grain of barley, rye, wheat, mineral and vitamin supplements, phosphorus acid ammonium salts.

Table 35. Daily ration for dairy cows in different seasons, kg d^{-1} (weight, 500 kg; productivity, 5-6 L d^{-1}).

Component of ration	Amount, kg day^{-1}
Stable period	
Hay	4
Straw	2
Silage	15
Beet roots	3
Concentrates	2
Pasture period	
Grass stand	50
Concentrates	2

Table 36. Ration of pigs, kg d^{-1} (weight 80 - 120 kg).

Components of ration	Amount, kg d^{-1}
Winter period	
Concentrates	2
Beet roots	6
Ground hay	0.2
Summer period	
Concentrates	2.8
Grass (legumes)	5.5

Concentrates include meals (barley, oats, wheat, pea); bran (wheat, meat, meat + bone or fish meal) and mineral supplements.

Table 37. Feed proportions in rations for hens, % (Consumption 110-140 g d^{-1} per capita).

Feeds	% feed in ration
Grain, unbroken (barley, oat, rye)	35-40
Grain, crushed or ground	30-35
Animal feeds (dry)	7-8
Green or succulent	20
Mineral supplements (gravium not included)	3

Table 38. Yields in 1986 for the agricultural area AGRO1, Novozybkov District.

Crop	Yield, kg m^{-2}
Cereals	0.19
Vegetables	2.3
Potatoes	2.0
Root vegetables	2.8

Table 39. Average milk production per cow in 1986.

Agricultural area	District	Milk production, L a^{-1}
AGRO 1	Novozybkov	2,600

Table 40. Distribution of agricultural lands in the test area by ^{137}Cs contamination.

Contamination level kBq m^{-2}	Contaminated area, km^2		
	plough land	hay pasture	total
37-185	3	5	8
185-370	72	16	88
370-555	96	49	145
555-1,100	161	90	251
1,100-1,480	37	19	56
1,480-2,960	25	26	51

Table 41. Distribution of agricultural subareas by contamination density.

Agricultural subarea	Land use	Area, Ha	Contamination level, kBq m^{-2}						
			<37	37-185	185-370	370-555	555-1110	1110-1480	>1,480
AGRO1-1	Arable land	1,953	-	-	380	1,498	75	-	-
	Pasture	526	-	-	-	526	-	-	-
	Total	2,479	-	-	380	2,024	75	-	-
AGRO1-2	Arable land	1,732	-	-	487	1,176	69	-	-
	Pasture	554	-	-	-	554	-	-	-
	Total	2,286	-	-	487	1,730	69	-	-
AGRO1-3	Arable land	2,177	-	-	-	457	1,720	-	-
	Pasture	814	-	-	190	87	393	144	-
	Total	2,991	-	-	190	544	2,113	144	-
AGRO1-4	Arable land	1,896	-	-	10	-	-	1,644	128
	Pasture	922	-	-	-	125	429	221	-
	Total	2,818	-	-	10	125	429	1,865	128
AGRO1-5	Arable land	1,580	-	-	-	-	42	148	1,390
	Pasture	1,452	-	-	-	-	206	141	1,105
	Total	3,032	-	-	-	-	248	289	2,495
AGRO1-6	Arable land	1,306	-	-	71	102	94	574	465
	Pasture	1.231	-	-	-	-	82	554	595
	Total	2,537	-	-	71	102	176	1,128	1,060
AGRO1-7	Arable land	2,104	-	-	-	21	1,865	218	-
	Pasture	2,024	-	-	136	289	1,599	-	-
	Total	4,128	-	-	136	310	3,464	218	-
AGRO1-8	Arable land	4,064	36	86	2,810	970	162	-	-
	Pasture	1,328	-	93	206	777	252	-	-
	Total	5,392	36	179	3,016	1,747	414	-	-
AGRO1-9	Arable land	3,151	-	63	980	1,100	1,008	-	-
	Pasture	1,493	-	194	337	738	224	-	-
	Total	4,644	-	257	1,317	1,838	1,232	-	-
AGRO1-10	Arable land	1,163	-	-	-	-	77	531	555
	Pasture	916	-	66	-	-	-	379	471
	Total	2,079	-	66	-	-	77	910	1,026
AGRO1-11	Arable land	2,514	-	-	-	-	1,674	840	-
	Pasture	1,963	-	-	-	177	1,388	80	318
	total	4,477	-	-	-	177	3,062	920	318
AGRO1-12	Arable land	2,717	-	-	-	-	2,159	558	-
	Pasture	2,132	-	-	120	125	1,793	94	-
	Total	4,849	-	-	120	125	3,952	652	-
AGRO1-13	Arable land	2,202	-	132	1,708	362	-	-	-
	Pasture	465	-	37	234	194	-	-	-
	Total	2,667	-	169	1,942	556	-	-	-
AGRO1-14	Arable land	1,573	-	-	90	114	1,369	-	-
	Pasture	758	-	91	-	-	573	94	-
	Total	2,331	-	91	90	114	1,942	94	-
AGRO1-15	Arable land	1,615	-	-	144	1,326	145	-	-
	Pasture	473	-	-	40	97	336	-	-
	Total	2,088	-	-	184	1,423	481	-	-
AGRO1-16	Arable land	2,765	-	-	-	-	2,478	287	-
	Pasture	1,514	-	-	181	561	678	94	-
	Total	4,279	-	-	181	561	3,156	381	-
AGRO1-17	Arable land	441	-	-	-	-	35	406	-
	Pasture	165	-	-	-	-	36	129	-
	Total	606	-	-	-	-	71	535	-

Table 41. (continued)

Agricultural subarea	Land use	Area, Ha	Contamination level, kBq m^{-2}						
			<37	37-185	185-370	370-555	555-1110	1110-1480	>1,480
AGRO1-18	Arable land	2,372	-	-	500	1,564	308	-	-
	Pasture	467	-	-	-	51	386	30	-
	Total	2,839	-	-	500	1,615	694	30	-
AGRO1-19	Arable land	2,092	-	-	25	896	1,171	-	-
	Pasture	1,280	-	-	50	288	786	156	-
	Total	3,372	-	-	75	1,184	1,957	156	-

Table 42. ^{137}Cs vertical distribution on various agricultural lands, % (1990).

Depth, cm	Agricultural lands			
	Plough land	Pasture	Dry meadow	Flooded meadow
0-5	25.0	88.2	97.9	76.8
5-10	25.8	6.0	1.2	17.4
10-15	30.1	2.9	0.3	2.3
15-20	18.6	1.4	0.1	2.6
20-25	0.3	0.7	0.2	0.4
25-30	0.1	0.5	0.2	0.2
30-40	0.0	0.2	0.1	0.2
40-50	0.0	0.1	0.0	0.1

Table 43. Age distribution of population on 31 December by 5-year intervals.

Age group, years	Women (%)	Men (%)
0-4	6.6	8.0
5-9	6.3	7.5
10-14	6.1	7.2
15-19	5.7	6.9
10-24	5.5	6.6
25-29	6.8	8.3
30-34	7.1	8.5
35-39	6.4	7.6
40-44	6.4	4.6
45-49	5.1	5.3
50-54	6.4	5.3
55-59	7.2	6.2
60-64	8.1	6.4
65-69	5.3	5.4
70-74	3.8	2.4
75-79	3.8	1.6
80-84	2.18	1.3
85-89	0.9	0.62
90-94	0.24	0.22
>95	0.08	0.06

Table 44. Distribution of adult rural inhabitants of the test area according to dwelling type and occupation group (for external dose evaluation).

Dwelling type	Occupation group, %		
	Indoor	Outdoor	Pensioners
One-storey wooden house	18	33	19
One-storey brick house	8	14	8

Table 45. Seasonal values of occupancy factors for rural environment, relative units.

Indoor workers, November-March				
Type of location	Mean	5th quintile	95th quintile	Std. dev.
Living area (indoors)	0.59	0.49	0.70	0.066
Living area (outdoors)	0.11	0.00	0.28	0.080
Work area (indoors)	0.24	0.13	0.30	0.056
Work area (outdoors)	0.05	0.00	0.10	0.039
Ploughed field	0.00	-	-	-
Virgin land	0.00	-	-	-
Rest area	0.01	0.000	0.03	0.009
Indoor workers, April-October				
Living area (indoors)	0.42	0.27	0.58	0.100
Living area (outdoors)	0.28	0.10	0.50	0.120
Work area (indoors)	0.23	0.07	0.31	0.077
Work area (outdoors)	0.02	0.000	0.17	0.061
Ploughed field	0.02	0.000	0.16	0.069
Virgin land	0.01	0.000	0.02	0.018
Rest area	0.02	0.000	0.10	0.035
Outdoor workers, November-March				
Living area (indoors)	0.55	0.33	0.73	0.106
Living area (outdoors)	0.11	0.000	0.33	0.093
Work area (indoors)	0.12	0.000	0.36	0.142
Work area (outdoors)	0.10	0.000	0.33	0.123

Table 45. (continued)

Outdoor workers, November-March				
Type of location	Mean	5th quintile	95th quintile	Std. dev.
Ploughed field	0.10	0.000	0.38	0.147
Virgin land	0.02	0.000	0.21	0.071
Rest area	0.00	-	-	-
Outdoor workers, April-October				
Living area (indoors)	0.42	0.31	0.61	0.097
Living area (outdoors)	0.19	0.04	0.33	0.099
Work area (indoors)	0.05	0.000	0.31	0.100
Work area (outdoors)	0.07	0.000	0.33	0.115
Ploughed field	0.21	0.000	0.50	0.187
Virgin land	0.04	0.000	0.28	0.086
Rest area	0.02	0.000	0.08	0.062
Pensioners, November-March				
Living area (indoors)	0.84	0.67	0.96	0.096
Living area (outdoors)	0.15	0.04	0.33	0.093
Work area (indoors)	0.00	-	-	-
Work area (outdoors)	0.00	-	-	-
Ploughed field	0.00	-	-	-
Virgin land	0.00	-	-	-
Rest area	0.01	0.000	0.013	0.013
Pensioners, April-October				
Living area (indoors)	0.56	0.34	0.85	0.144
Living area (indoors)	0.40	0.16	0.60	0.129
Work area (indoors)	0.00	-	-	-
Work area (outdoors)	0.00	-	-	-
Ploughed field	0.00	-	-	-
Virgin land	0.00	-	-	-
Rest area	0.04	0.000	0.14	0.055

Table 46. Annual Average occupancy factors for the rural population.

Type of location	Occupancy factors, relative units		
	Indoor workers	Outdoor workers	Pensioners
Living area (indoors)	0.49	0.47	0.68
Living area (indoors)	0.21	0.16	0.30
Work area (indoors)	0.23	0.08	0.00
Work area (outdoors)	0.03	0.08	0.00
Ploughed field	0.02	0.17	0.00
Virgin land	0.01	0.03	0.00
Rest area	0.01	0.01	0.02

Table 47. Food consumption rate by the adult rural inhabitants of the test area before the Chernobyl accident, kg d^{-1} (Mean ± SD).

Food origin	Sex	Milk	Meat*	Potato*	Vegetables*	Bread
Local	Male	0.76 ± 0.78	0.177 ± 0.099	0.64 ± 0.30	0.30 ± 0.11	-
	Female	0.56 ± 0.48	0.170 ± 0.122	0.56 ± 0.22	0.27 ± 0.09	-
Imported	Male	0.016	0.020	0.005	0.003	0.39 ± 0.16
	Female	0.016	0.016	0.006	0.005	0.29 ± 0.12

* Mass of raw product. Actual consumption is less by 20-30%.

Table 48. Consumption rate of natural food products by the population surveyed in the villages of the test area, g d^{-1}.

Area, Time period	Gender	Number of respondents	Wild mushrooms*	Forest berries
"Controlled", Nov. 1994	Male	59	18	3.4
	Female	74	9	4.0
"Controlled", Oct. 1994	Male	67	15	3.7
	Female	34	11	6.2
"Observed" Oct. 1995	Male	58	33	12
	Female	103	25	12

* Mass of raw product. Actual consumption is less by 20-30%.

Note: Average fish consumption in 1994-1996 is 18 g d^{-1}.
The average uncertainty for consumption of natural food products is 40-60%.

Table 49. Mean daily consumption of major locally produced food products by inhabitants of the "Controlled Area" before and after the Chernobyl accident, kg d^{-1} or L d^{-1} (Mean ± SE).

Year	Gender	Local food product				
		Milk	Meat*	Potato*	Vegetables *	Bread
1985	M	0.80 ± 0.07	0.174 ± 0.010	0.60 ± 0.02	0.30 ± 0.01	0.40 ± 0.02
	F	0.59 ± 0.03	0.186 ± 0.010	0.53 ± 0.02	0.27 ± 0.01	0.28 ± 0.01
10 May 1986	M	0.66 ± 0.07	0.082 ± 0.010	0.60 ± 0.02	0.30 ± 0.01	0.40 ± 0.02
	F	0.56 ± 0.07	0.088 ± 0.010	0.53 ± 0.02	0.27 ± 0.01	0.28 ± 0.01
20 May 1986	M	0.46 ± 0.04	0.072 ± 0.010	0.60 ± 0.02	0.30 ± 0.01	0.40 ± 0.02
	F	0.38 ± 0.04	0.082 ± 0.010	0.53 ± 0.02	0.27 ± 0.01	0.28 ± 0.01
June 1986	M	0.45 ± 0.05	0.072 ± 0.007	0.60 ± 0.02	0.30 ± 0.01	0.40 ± 0.02
	F	0.37 ± 0.03	0.082 ± 0.008	0.53 ± 0.02	0.27 ± 0.01	0.28 ± 0.01
July 1986	M	0.40 ± 0.04	0.072 ± 0.007	0.60 ± 0.02	0.30 ± 0.01	0.40 ± 0.02
	F	0.35 ± 0.03	0.081 ± 0.008	0.53 ± 0.02	0.27 ± 0.01	0.28 ± 0.01
August 1986	M	0.36 ± 0.04	0.072 ± 0.007	0.60 ± 0.02	0.30 ± 0.01	0.40 ± 0.02
	F	0.34 ± 0.03	0.081 ± 0.008	0.53 ± 0.02	0.27 ± 0.01	0.28 ± 0.01
September 1986	M	0.15 ± 0.02	0.034 ± 0.02	0.60 ± 0.02	0.30 ± 0.01	0.34 ± 0.02
	F	0.16 ± 0.02	0.042 ± 0.004	0.53 ± 0.02	0.27 ± 0.01	0.28 ± 0.01
1987	M	0	0.030 ± 0.003	0.55 ± 0.04	0.30 ± 0.01	0.40 ± 0.02
	F	0	0.041 ± 0.004	0.48 ± 0.04	0.27 ± 0.01	0.28 ± 0.01
1988	M	0	0.028 ± 0.003	0.55 ± 0.04	0.30 ± 0.01	0.40 ± 0.02
	F	0	0.041 ± 0.004	0.48 ± 0.04	0.27 ± 0.01	0.28 ± 0.01
1990	M	0	0.010 ± 0.004	0.50 ± 0.04	0.25 ± 0.04	0.36 ± 0.03
	F	0	0.016 ± 0.003	0.39 ± 0.02	0.21 ± 0.01	0.28 ± 0.01
1993	M	0.13 ± 0.06	0.148 ± 0.020	0.84 ± 0.02	0.29 ± 0.02	0.40 ± 0.02
	F	0.11 ± 0.04	0.095 ± 0.013	0.63 ± 0.03	0.28 ± 0.02	0.31 ± 0.01
1994	M	0.24 ± 0.05	0.164 ± 0.012	0.81 ± 0.05	0.21 ± 0.01	0.41 ± 0.02
	F	0.29 ± 0.04	0.109 ± 0.086	0.70 ± 0.39	0.18 ± 0.01	0.34 ± 0.02

* Mass of raw product. Real consumption is less by 20-30%.

Table 50. Mean daily consumption of major locally produced food products by inhabitants of the "Observed Area" ("Non-Controlled Area") before and after the Chernobyl accident, kg d^{-1} or L d^{-1} (Mean ± SE).

Year	Gender	Local food product				
		Milk	Meat*	Potato*	Vegetable*	Bread
1985	M	0.70 ± 0.07	0.186 ± 0.01	0.69 ± 0.04	0.31 ± 0.01	0.38 ± 0.02
	F	0.55 ± 0.03	0.161 ± 0.08	0.58 ± 0.02	0.27 ± 0.01	0.29 ± 0.01
10 May 1986	M	0.54 ± 0.03	0.140 ± 0.01	0.69 ± 0.04	0.31 ± 0.01	0.38 ± 0.02
	F	0.48 ± 0.04	0.105 ± 0.01	0.58 ± 0.02	0.27 ± 0.01	0.29 ± 0.01
20 May 1986	M	0.39 ± 0.04	0.140 ± 0.01	0.69 ± 0.04	0.31 ± 0.01	0.38 ± 0.02
	F	0.30 ± 0.03	0.105 ± 0.01	0.58 ± 0.02	0.27 ± 0.01	0.29 ± 0.01
June 1986	M	0.38 ± 0.04	0.140 ± 0.01	0.69 ± 0.04	0.31 ± 0.01	0.38 ± 0.02
	F	0.29 ± 0.03	0.105 ± 0.01	0.58 ± 0.02	0.27 ± 0.01	0.29 ± 0.01
July 1986	M	0.37 ± 0.04	0.140 ± 0.01	0.69 ± 0.04	0.31 ± 0.01	0.38 ± 0.02
	F	0.27 ± 0.03	0.105 ± 0.01	0.58 ± 0.02	0.27 ± 0.01	0.29 ± 0.01
August 1986	M	0.38 ± 0.04	0.140 ± 0.01	0.69 ± 0.04	0.31 ± 0.01	0.38 ± 0.02
	F	0.27 ± 0.03	0.105 ± 0.01	0.58 ± 0.02	0.27 ± 0.01	0.29 ± 0.01
September 1986	M	0.36 ± 0.04	0.124 ± 0.01	0.69 ± 0.04	0.31 ± 0.01	0.38 ± 0.02
	F	0.26 ± 0.03	0.084 ± 0.008	0.58 ± 0.02	0.27 ± 0.01	0.29 ± 0.01
1987	M	0.35 ± 0.04	0.124 ± 0.01	0.52 ± 0.05	0.31 ± 0.01	0.38 ± 0.02
	F	0.25 ± 0.03	0.084 ± 0.008	0.53 ± 0.05	0.27 ± 0.01	0.29 ± 0.01
1988	M	0.36 ± 0.04	0.124 ± 0.01	0.52 ± 0.05	0.31 ± 0.01	0.38 ± 0.02
	F	0.24 ± 0.03	0.084 ± 0.008	0.53 ± 0.05	0.27 ± 0.01	0.29 ± 0.01
1990	M	0.20 ± 0.05	0.044 ± 0.006	0.45 ± 0.03	0.21 ± 0.02	0.29 ± 0.02
	F	0.15 ± 0.02	0.058 ± 0.006	0.46 ± 0.02	0.23 ± 0.01	0.28 ± 0.01
1993	M	0.35 ± 0.06	0.150 ± 0.018	0.84 ± 0.05	0.26 ± 0.02	0.37 ± 0.03
	F	0.39 ± 0.04	0.116 ± 0.008	0.66 ± 0.03	0.29 ± 0.02	0.30 ± 0.02
1994	M	0.57 ± 0.09	0.160 ± 0.026	0.77 ± 0.08	0.29 ± 0.02	0.53 ± 0.05
	F	0.52 ± 0.05	0.107 ± 0.007	0.59 ± 0.03	0.20 ± 0.01	0.48 ± 0.02

* Mass of raw product. Real consumption is less by 20-30%.

Table 51. Percent of adult rural inhabitants of the test region consuming local fish before and after the Chernobyl accident.

Time	Sex	Number	No (%)	Yes (%)
Before accident (total area)	Male	196	54	46
	Female	390	60	40
1986-87 (Controlled Area)	Male	83	86	14
	Female	165	92	8
1986-87 (Observed Area)	Male	102	56	44
	Female	198	55	45
1990 (total area)	Male	110	86	14
	Female	300	89	11
1993 (total area)	Male	71	61	39
	Female	141	75	25
1994 (Controlled Area)	Male	76	59	41
	Female	112	78	22
1995 (settlement Voronok)	Male	40	58	42
	Female	86	62	38

Table 52. Percent of adult rural inhabitants of the test region consuming mushrooms before and after the Chernobyl accident.

Territories	Sex	Number	No (%)	Yes (%)
Before accident (total area)	Male	195	30	70
	Female	391	29	71
1986-87 (Controlled Area)	Male	83	52	48
	Female	165	57	43
1986-87 (Observed Area)	Male	102	54	46
	Female	198	50	50
Settlement Korchi, 1994	Male	22	27	73
	Female	21	57	43
Settlement Shelomii, 1994	Male	38	32	68
	Female	53	38	62
Settlement Gordeevka, 1994	Male	67	30	70
	Female	34	20	80
Settlement Voronok, 1995	Male	58	16	84
	Female	103	19	81

Table 53. Provisional limits for radionuclide concentrations in foodstuffs and drinking water in the Chernobyl-affected areas, Bq kg^{-1}.

Foodstuffs	30.05.86	10.06.88	22.01.91	1993
	total beta-activity	$^{137}Cs + ^{134}Cs$	^{137}Cs	^{137}Cs
Drinking water	370	18.5	18.5	-
Milk	370* (since 1.08.86)	370	370	370
Cheese	7,400	370	370	370
Butter	7,400	1,110	370	
Condensed milk	18,500	1,110	1,110	
Meat and fish products	3,700	1,850	740	600
Eggs	1,850 per one egg	1,850	740	-
Bread, cereals	370	370	370	370
Sugar	1,850	370	370	-
Vegetables, fruit, juices	3,700	740	590	- -
Mushrooms	18,500	1,850	1,480	600
Wild berries	3,700	1,850	1,480	600
Baby food	-	370	185	185

Note: * before August, 1986: 3,700 Bq L^{-1}.

Table 54. Effectiveness of agrotechnical countermeasures.

Agrotechnical countermeasures	Soil category	Grass as a crop type	Reduction in root uptake transfer
Rotary cultivation or disking	Soddy-podzolic sandy, sandy loam Peaty	Natural meadow	1.2-1.5 1.3-1.8
Ploughing	Soddy-podzolic sandy, sandy loam Peaty	Natural meadow	1.8-2.5 2.0-3.2
Ploughing with turnover of the upper layer	Soddy-podzolic sandy, sandy loam Peaty	Natural meadow	8.0-12.0 10.0-16.0
Radical improvement	Soddy-podzolic sandy, sandy loam Peaty	Natural meadow Perennial grasses Natural meadow Perennial grasses	2.7-5.3 2.3-4.6 2.9-6.2 3.9-11.2
Superficial improvement	Soddy-podzolic sandy, sandy loam Peaty	Natural meadow Perennial grasses Natural meadow Perennial grasses	1.6-2.9 1.3-1.8 1.8-3.1 1.5-2.7

Table 55. Effectiveness of agrochemical countermeasures.

Agrochemical countermeasures	Soil category	Crop type	Reduction in root uptake transfer
Liming	Soddy-podzolic sandy, sandy loam	Barley, winter rye, oats, maize silage, potato, beet roots, vegetable	1.8-2.3
Application of increased doses of P-K fertilizers	Soddy-podzolic sandy, sandy loam	Barley, winter rye, oats, maize silage, potato, beet roots, vegetable	1.2-2.2
Application of organic fertilizers	Soddy-podzolic sandy, sandy loam	Barley, winter rye, oats, maize silage, potato, beet roots, vegetable	1.3-1.6
Application of clay minerals	Soddy-podzolic sandy, sandy loam	Barley, winter rye, oats, maize silage, potato, beet roots, vegetable	Dubious effect, in light soils results mainly in 1.5-3.0 fold decrease of radionuclide accumulation by plants
Combined application of lime, organic and mineral fertilizers	Soddy-podzolic sandy, sandy loam	Barley, winter rye, oats, maize silage, potato, beet roots, vegetable	2.5-3.5

Table 56. Effectiveness of countermeasures in animal breeding (Application of sorbents).

Type of treatment	Product	Dosage	Reduction factor
Ferrocine	Milk	3-6 g per day	3-5
	Meat(cows)	3-6 g per day	2-3
	Meat (sheep)	0.5-1 g per day	3-4
Boli ferrocine	Milk	2-3 boli per 3	2-3
Bifege ferrocine	Milk	40 g per day	2-4

Table 57. Effectiveness of food processing options.

Raw product	Type of processing	Reduction (Bq kg^{-1} per Bq kg^{-1})
Milk	Milk to butter	2.5-15
	Milk to cheese	0.4-2
	Milk to cream	0.5-1.7
	Milk to skimmed milk	1.0-1.1
Meat	Soaking	1.4-2.0
	Salting	2.0-3.3

Tables 58. Effectiveness of various countermeasures in agriculture.

Groups of protective measures	Reduction factor	
	Range	Best estimates
Amelioration of meadows and pastures	2.5–8.0	3
Application of mineral fertilisers	1.2-2.5	1.5
Liming of acid soil	1.5-2.0	1.7
Technological processing of milk into butter	2.5–15	10
Application of Prussian blue	2–5	3
Crop selection according to ^{137}Cs accumulation	up to 4.5	3

Table 59. Agrochemical measures in the test area (Novozybkov district, agricultural areas), 1986-1989.

Agrochemical Measures	1986	1987	1988	1989
Lime:				
area treated, km^2	271	206	108	105
application, kg m^{-2}	0.73	0.67	0.75	0.84
Phosphorite:				
area treated, km^2	92	100	51	52
application, kg m^{-2}	0.13	0.14	0.16	0.15
Mineral fertilizers active matter), 10^6 kg:				
N	8.1	8.3	7.0	8.1
P	5.1	5.7	4.9	6.7
K	8.3	12.3	10.0	12.2
Total NPK:				
area treated, km^2	460	600	450	600
application, kg m^{-2}	0.033	0.031	0.034	0.034
Organic fertilizers				
area treated, km^2	169	128	145	145
application, kg m^{-2}	7.0	8.5	7.9	7.9

Table 60. Radical amelioration of natural forage land in the test area (Novozybkov district, agricultural area AGRO1), 1986-1990.

Year	Cumulative percentage of re-cultivated haylands and pastures
1986	6.4
1987	14.0
1988	35.7
1989	64.6
1990	95.4

Table 61. Contribution of agricultural and natural products to internal dose of Shelomy, %. (Average data for 1991-1995).

Cohort of habitants	Products				Internal dose, mSv (1995)
	Milk	Meat	Potato	Mushrooms	
Consuming private milk	55.3	16.0	4.8	21.0	0.97
Consuming milk from shop	7.8	18.0	9.2	60	0.34
All inhabitants	20	14.0	7.8	53	0.44

Table 62. Mean effectiveness of annual external dose reduction for inhabitants of the villages decontaminated in 1989.

Population group	Outdoor workers	Indoor workers, Pensioners, and Schoolchildren	Pre-school children	Mixed * group
Dose reduction factor	1.2	1.3	1.4	1.3

* 40% outdoor workers, 20% indoor workers, 15% pensioners, 15% schoolchildren, 10% pre-school children.

DATA FOR MODEL TESTING AND COMPARISON

SAMPLING OF AGRICULTURAL AND ENVIRONMENTAL COMPONENTS

Soil Sampling

Soil sampling on non-arable agricultural land

Soil samples were collected up to the moment of grass vegetation onset and during grass harvest. Prior to soil sampling, at the control site, the exposure dose rate of gamma radiation was measured at heights of 1 m and 3-4 cm above the ground. At the site, 5 points were selected with a frequently observed exposure dose rate of gamma radiation, one next to the center and the rest at its periphery. Sampling at control sites was carried out with a standard ring 5 cm in height and 14 cm in diameter or a sampler 10 cm in height and 11-14 cm in diameter.

Sampling on arable agricultural land

Soil samples on arable land were collected prior to the beginning of spring field work and just before harvesting. Prior to soil sampling, at the control site, the exposure dose rate of gamma radiation was measured at heights of 1 m and 3-4 cm above the ground. Each sample collected at the control site was made of 10 or more individual samples, uniformly taken throughout the whole area of the site. When a coring tube was used for sampling, the number of pricks depended on the diameter of its operating part. All samples were then bulked, and a combined soil sample of no less than 2 kg in weight was compiled by the quartering method. The sampling depth of individual samplers was required to correspond to the depth of the arable layer (depth of basic soil cultivation). Recommended standards for sample number are summarized in Table 63.

Table 63. Recommended standards for collecting mixed samples.

^{137}Cs density of contamination, kBq m^{-2}	Maximum area to obtain a combined sample
<37	5 samples per administrative district
37-185	1 sample per elementary site*
185-555	1 sample per 400 ha
555-1480	1 sample per 100 ha
>1480	1 sample per 50 ha

* An elementary site is a field occupied by one crop

Collection of Plants and Plant Product Samples

Plant sampling at control sites

For sampling at control sites, it is essential that plant sampling be done in conjunction with soil sampling, i.e., both plant and soil samples are collected at the same site and time. Plant samples were collected at harvest time. For a combined plant sample of no less than 1 kg in weight, no fewer than 10 point (individual) samplings are recommended. The above-ground part of plants was cut at a height of 3-4 cm, without soil loading. The samples were placed on plastic film or paper. A combined sample is made of either the entire plant or separate parts, e.g., stems, leaves, fruit, grain, roots. The weight of a combined sample depends on the crop species.

Grain sampling

Grain sampling from a lorry was performed with a mechanical sampler or by hand with a probe. The number of sampling points depends on the body length of the lorry and amounts to 4-8 samples. Samples were collected at a distance of 0.5-1 m from the front and rear of the lorry and 0.5 m from the sides of the lorry. Point samples with a mechanical sampler were taken throughout the whole depth of the grain bulk. Point samples with a hand probe were taken from the upper and lower layers. In lorry trains, samples were collected from each trailer. The overall weight of the averaged sample was no less than 1-2 kg. Samples from loading or unloading of grain into vans, ships, warehouses and elevators were collected from the grain stream at the point of the drop with a mechanical sampler or special cup by crossing the stream at regular intervals during the whole period of lot movement. The weight of one point sample was no less than 100 g. Point sampling of grain from bags depended on the number of bags in a lot, from each second bag to each tenth. From sewn bags, point samples were taken by bag probe at three accessible points. A combined sample is a set of point samples. The total weight of point samples was no less than 2 kg.

Sampling of roots, tubers and potatoes

Samples of tubers and roots were collected from piles, bulks, heaps, lorries, trailers, vans, barges, storage facilities, etc. Point samples were taken along the diagonal of the site surface of a pile, bulk, or heap, or the central line of the body of a lorry, trailer, van, etc., at regular intervals at a depth of 20-30 cm. Tubers and roots were collected at three consecutive points (arbitrarily) by hand. Each point sample was 1-1.5 kg in weight. Combining the point samples yielded a combined sample. Of the latter, an averaged sample no less than 2 kg in weight was taken for analyses, with a preliminary sorting of roots and tubers by size.

Sampling of Fodder for Farm Animals

Fodder sampling was carried out at sites of its growing, production, storing or animal feeding. The weights (volumes) of average samples for radiological studies necessary to ensure that the error was no more than ± 50% are listed in Tables 64 and 65.

Table 64. Weights or volumes of samples necessary for various measuring techniques.

Technique to determine specific activity (A_{sp})	Ranges of A_{sp} of controlled products, Bq kg^{-1}	
	0.037-18.5	Above 18.5
^{137}Cs gamma-radiometry express-method		0.5-1.0 L or kg
^{137}Cs gamma-spectrometry a – native material b – ash residue	 1.0 L or kg 1.0-3.0 L or kg	0.3-0.5 L or kg
Radiochemical method and others	0.2-3.0 L or kg	0.2-0.5 L or kg

Table 65. Sampling rates for fodder (rough, succulent, concentrates, root-tuber) by lot size.

Lot weight, t	Number of samples
Below 5.0	1
5.1-10.0	2
10.1-15.0	3
15.1-20.0	5
20.1-50.0	7
50.1-80.0	9
80.1-100.0	10
101-10000	1 extra sample per each 100 t above 100 t
Above 10000	1 extra sample per each 200 t

Grass and green mass of farm crops

Grass samples from pastures or haylands were collected immediately before pasturing of animals or harvesting for fodder. To this end, at the site selected for sampling, 8 to 10 registration plots were identified, about 1 or 2 m^2 in size. Point samples were collected along the diagonal of a square 100 m on each side at a rate of 10-12 samples, each 0.4-0.5 kg in weight. The grass stand was harvested (cut) at a 3-5 cm height. The point samples were bulked and mixed.

From the green mass delivered for livestock feeding or for making silage and haylage, or from dried fodder, no fewer than 10-15 samples were taken from different points. The weight of a point sample was 0.4-0.5 kg. The point samples were mixed, and arranged into an even layer, and then average samples were collected by means of quartering.

Rough fodder (hay, straw)

Point samples from hay or straw lots stored in stacks and ricks were collected along the perimeter at equal intervals at a height of 1-1.5 m above the ground on all accessible sides at a depth of no less than 0.5 m. Point samples were bulked to produce a combined sample of 2 kg in weight. For this purpose, point samples were arranged in an even layer (3-4 cm) on a tarpaulin and carefully mixed to exclude plant breaking and plant dust formation. An average sample was then taken for analysis from the combined sample. To this end, wisps of hay 60-120 g in weight were collected from no fewer than 10 sites across the whole width and length of the layer. An average 1 kg sample was packed into a sturdy paper or plastic bag.

For sampling of fodder from pressed bales (rolls), the following samples were taken: from a lot up to 15 tons, 3% of the bales; above 15 tons, 1%. Point samples of 0.2-0.3 kg were taken from each bale (roll) from different strata and then arranged on a tarpaulin, where they were mixed and an average sample was isolated.

Silage, haylage

Samples were collected no sooner than 4 weeks after making. Point samples from trenches and towers were collected by a sampler at a depth of 2 m and carefully mixed. An average sample was taken from a combined one by a square method.

Roots, tubers

Sampling was performed from fields, piles, warehouses, storages, lorries, etc. From a packed lot (bags, boxes, etc.), a sample consisted of 2.5% of the packages, but no fewer than 3; from piles, bulk point samples were taken from different layers, 10-15 each, and along the perimeter. These were then mixed to yield an average sample from the combined sample.

Concentrates (mixed feed, grain fodder, oilcake, etc.)

Samples were collected by a scoop or cone probe in staggered order from different layers. When samples were taken from bags, 3 to 5.5 package units were sampled. Point samples were collected from each sampling unit at 3 points. These were then combined and carefully mixed, and average samples were obtained by quartering.

Sampling of Animal Products

Milk and liquid milk and sour milk products

Sampling of milk and of liquid milk and sour milk products was performed at sites of their production, processing, storage, or sale. Prior to sampling, milk was carefully mixed for 1 to 20 min, depending on the reservoir volume. Point samples from different points of the reservoir were taken with a mug, scooper (0.5 L capacity), or metal (or plastic) tube with an inner diameter of 10 mm. The same number of samples (no less than 3), was taken from each reservoir. Pouring the point samples taken from one reservoir together yielded a combined sample. After mixing, an average sample of a required volume was collected and sent to the laboratory for examination.

Sour cream, cottage cheese and curds

In sampling of sour cream, cottage cheese or curds packed in large or transportation containers, 10% of the containers were opened and sampled as controls. When fewer than 10 units were available, one was opened. Depending on the consistency of the sour cream, sampling was carried out by a scooper, probe or tube, dipped to the container bottom. Point samples were combined into one clean reservoir, carefully mixed (if needed, by heating to 35ºC). Then an average sample was taken.

Meat, meat products

Samples of meat and meat products were collected from farms, markets, meat packing plants and cold stores. In meat packing plants and cold stores, sampling from each homogeneous lot included 10% of the carcasses (half-carcasses) of cattle, 5% of the carcasses of sheep and pigs, or 25 frozen or cooled blocks of meat and products, but no fewer than 3. Point samples were taken from each sample carcass or its part as a whole piece of meat of 200 g in weight.

A combined sample was derived from the point samples. The weight of the combined sample depended on the specific activity of the samples and the examination procedure. To form an average 0.2-0.3 kg sample, meat was cut into small pieces (10-15 g) with a knife or minced and then mixed.

Sampling of Aquatic Components

Standard methods were applied for sampling of water and other aquatic objects (Makhonko, 1990). Most of the water samples were collected in the near-surface water layers at a depth of 0.2-0.6 m. Water was passed through fine-pore filters to separate suspended particles larger than 10^{-6} m in size. Upon completion of the filtration, the filters were slightly dried, placed in sealed porcelain crucibles and incinerated in a muffle furnace at a temperature of 400-500 ^{o}C. The filtered water samples were passed through ion-exchange resin columns with a grain size of 0.5-1 mm. Then the resins removed from the columns were packed in measuring containers for spectrometric analysis.

Samples of bottom sediments were collected using special samplers of two types designed and manufactured at SPA "Typhoon", and a pneumatic sampler. The collected samples were analyzed in layers of a thickness of 1-2 cm each. The first type of sampler was a duralumin tube, 12 cm in diameter and 70 cm long. The sampler was pressed into the bottom sediment layer at the sampling site. Then the cores were treated in one of two ways, depending on the porosity of bottom sediments. At sufficiently small porosity, the bag with a core was removed from the tube and the core was separated with a knife into layers of the required thickness, which were further treated as individual samples. At large porosity (liquid bottom sediments), the core was separated into layers directly in the duralumin tube, beginning from the top and using a special spoon. Then the core layers were weighed and packed in plastic bags. After that, the samples were dried in the air or in a drying chamber at a temperature of no more than 100°C, weighed again, and packed in standard containers for spectrometric analysis.

The second type of sampler was a duralumin tube, 8.3 cm in diameter and up to 50 cm in length, attached to a rod. After sampling, the core was squeezed out with a piston and separated into layers. Then the samples were treated as with the first type of sampler. From the wet and dry weights of samples and the volume of wet samples, it was possible to determine the density of bottom sediment particles and their porosity. The error in the determination of ^{137}Cs concentrations by layers of bottom sediments includes errors of gamma-quantum count statistics and gamma spectrometer calibration, as well as errors in the determination of layer thickness (occurring in core separation into layers) and wet weight.

Fish samples were collected from the Iput River and from lakes. Preliminary preparation included determination of the species of a fish, measurement of its weight and length, and sampling of its muscles. The preparation of a sample for measurement of ^{137}Cs consisted in the preliminary concentrating of the sample by incineration or by acid decomposition of the organic component of the sample.

RADIOCESIUM MEASUREMENTS

Agricultural Sample Measurement

The measurements of agricultural production samples were carried out by the local authorities belonging to the system of Radiation Control of the Russian Ministry of Agricultural Production and the Russian Institute of Agricultural Radiology and Agroecology (RIARAE). The specific activity of radiocesium in samples was determined by standard methods established by the Ministry of Agricultural Production of the Russian Federation. Several different techniques were used for measurements: semiconductor and scintillation gamma spectrometry, and scintillation gamma radiometry; the measurement error was ± 15%. However, all sampling and measuring techniques were adopted by the organizations, which are responsible for measurement quality control and have the appropriate certificates. The specification of the detection blocks used for measurements is given in Table 66.

Table 66. Specifications of detection blocks for measurement techniques.

Registration technique	Energy range of radiation to be registered, MeV	Activity range of samples measured, Bq	Measurement geometry, sample dimension
Semiconductor and scintillation gamma spectrometry	0.05-3.0	$0.5\text{-}10^5$	Marinelli vessel 0.5 L; 1 L
Scintillation gamma radiometry	0.05-3.0	$0.5\text{-}10^5$	Marinelli vessel 0.5 L; 1 L; Petri dish 100 mm

In RIARAE, the specific activity of ^{137}Cs in samples was measured by Canberra γ-spectrometers with a superpure Ge-Li detector, measurement error being ± 10%. The quality of measurements provided by RIARAE was tested in the frame of the intercalibration procedure of the International Chernobyl Project. The intercalibration of results between the Russian authorities responsible for measurements of agricultural production and RIARAE was performed in 1991-1994. The results of measurements provided by the Ministry of Agricultural Production of the Russian Federation were analysed and adopted for official application by an Interministry commission which is responsible for the evaluation of the radiological situation in the territories of Russia subjected to contamination.

Estimation of ^{137}Cs concentrations in different species of mushrooms and berries

Data obtained at 15 stationary forest sites were used for the estimation of ^{137}Cs concentrations in different species of mushrooms and berries. The average ^{137}Cs contamination density of these sites differs from the average contamination density of forests located in the test area. Therefore, a two-step approach was applied for estimating the contamination of forest products for the whole test area. In the first stage, aggregated transfer factors values (T_{ag}) from soil to different species of berries or mushrooms were calculated as a ratio of the ^{137}Cs concentration (fresh mass) of berries or mushrooms (Bq kg^{-1}) to its deposition density on the soil-vegetation cover (kBq m^{-2}). In the second stage, the ^{137}Cs concentration in each species of berries and mushrooms was recalculated for the whole territory of the test area taking into account the deviation of individual T_{ag} values and the contamination of forests.

Environmental Sample Measurement

The activity of radiocaesium in environmental samples was determined by standard gamma-spectrometric methods with lead protection, using highly sensitive semiconductor detectors and multichannel pulse analyzers (Makhonko, 1990; Kryshev, 1996). Gamma-spectrometric analysis was performed using a Canberra 35+ type spectrometer equipped with a 7229P-type detector with an effective volume of 180 cm^3, and multichannel pulse analysers of the NOKIA LP-4900 type with semiconductor detectors with volumes of 60 cm^3 and 80 cm^3. Measuring errors did not exceed 20% for water, and 10% for bottom sediments and fish. Measurements of ^{137}Cs taken in the laboratories were subjected to intercalibration within the framework of the International Chernobyl Project.

EXPOSURE MEASUREMENTS

External Exposure

Effective external dose from deposited radionuclides

After the Chernobyl accident, individual external doses to members of the population were measured with TL-dosimeters distributed to the inhabitants of the most contaminated areas of Russia, including the test area. The measurements were performed with dosimeters based on TL-detectors of type DTG-4 (LiF:Mg,Ti; monocrystals 5 mm in diameter and 0.9 mm thick), produced by the Institute of Geochemistry, Irkutsk, Russia. Each dosimeter consists of two chips. The thickness of the plastic holder walls of the dosimeter corresponds to a surface density thickness of 1 g cm^{-2}. A Harshaw 2000-D reader was used to determine doses absorbed by the detectors. The detectors were calibrated in conditions of free-air geometry by gamma radiation with a reference source of ^{137}Cs at the St. Petersburg Centre of Metrology, Russia. The basic relative error of a reading did not exceed ± 15% per detector at the 95% confidence level. The detection limit, defined as the smallest value of dose that can be detected at a specified (95%) confidence level, was determined to be 30 μGy. The conversion factor c_i from readings of an individual dosimeter to the value of the effective dose was determined on the basis of irradiation experiments with physical anthropomorphic phantoms. Values of c_i were 0.9 Sv Gy^{-1} for adults.

TL-dosimeters were distributed with the help of the local administration to inhabitants of the contaminated area during the spring/summer time. They were used for a period of approximately one month (25-35 days). Corresponding doses per month were calculated by a simple time scaling. The inhabitants were instructed to wear the dosimeters all the time in a pocket or by a string around the neck. When a dosimeter was assigned, basic information on the person was registered, including name, age, sex, occupation, material of construction of the inhabitant's house (wood or brick), and number of stories. The TL signals accumulated during transport and storage before and after use were estimated with the help of control dosimeters, and subtracted from the total reading. Both the terrestrial and cosmic background radiation contributions were subtracted from the results of measurements. In accordance with the goals of the present work, we also subtracted from the dosimeter readings the contribution of ^{134}Cs gamma radiation in the dose. This contribution was assessed on the basis of the ratio of activities $^{134}Cs/^{137}Cs$ at the time of measurement (at the time of deposition, 28.04.1986, the ratio $^{134}A/^{137}A$ was 0.54).

Measurements of individual doses in the test area (the Novozybkov district of the Bryansk region) started in December 1986 and continued during all of 1987 by several series of 3 to 4 months each. Later, measurements were performed episodically during one month in different seasons of the year. The measurements were performed in the following rural settlements of the Novozybkov district (in parentheses, the soil contamination density with ^{137}Cs as of 28.04.1986 is given, MBq m^{-2}): Vereshaki (0.7); Svyatsk (1.49); Stary Vyshkov (1.47); VIUA (1.05); Novoye Mesto (1.04); Vnukovichi (0.71); Starye Bobovichi (1.04). During 1987, 215 measurements of individual doses were performed, during 1989 (May) 90 measurements, during 1991 (October) 105 measurements, and during 1992 (November) 259 measurements.

The measurement results for the indicated groups of the adult population during each time period were normalised for the soil contamination density (MBq m^{-2}) and were weighted in accordance with the composition of these groups in the representative sample for the investigated region. The obtained distribution of individual doses was approximated by the lognormal distribution and checked by means of Kolmogorov-Smirnov and Chi-Square tests. Table 67 presents the parameters of the distributions obtained for measured individual external doses. Table 68 gives the corresponding results, taking into account the variability of the soil contamination density in the investigated region (see section on dose calculations, below).

Internal Exposure

Whole body measurement technique

In 1986-88, on-site measurements of the internal content of cesium radionuclides in the body of inhabitants were performed mainly by means of scintillation radiometers SRP-68-01 produced in the USSR. Also, single-channel radiometers RFT-20046 (Robotron 20046) produced in the GDR with NaI(Tl) crystals 25 x 25 or 40 x 40 mm in size were applied. After 1988, the RFT radiometers were equipped with BDEG-type detectors produced in Russia and NaI(Tl) crystals 63 x 63 mm in size, to increase their sensitivity. Calibration factors and techniques for measurements with these devices were developed at the Leningrad Institute of Radiation Hygiene.

To perform whole body measurements at contaminated areas, premises were chosen with a low background level, usually multi-storey brick buildings. Measuring devices and the persons to be investigated were located in the place most remote from windows. Before the beginning of measurements, the background level (P_b, μR/hour or pulse/sec) was determined in the place where measurements of persons were performed.

Two variants of the measurement technique were used:

a) The investigated person sat on a chair and put his or her feet on a support about 20 cm high. The radiometer detector was put next to the lower part of the stomach. The investigated person bent, enveloping the detector with his or her body and holding it with his or her hands. The measurement time was 30 s if the arrow indicator of the SRP-68-01 device was used, or 100 s, if the device worked with pulse recording.

b) When investigating persons who had difficulties in bending (children below 3 years, pregnant women, obese and ill persons), the detection unit was put next to the loins of a standing person.

The content of cesium radionuclides in the bodies of inhabitants was calculated in accordance with the official technique developed during the first months after the Chernobyl accident:

$$A = K * T * (P - K_s * P_b)$$

where A is the content of caesium radionuclides in the body of the investigated person, μCi;
K is the calibration factor, μCi/(cm*μR/hour) for SRP-68-01 and μCi/(cm*pulse/sec) for Robotron 20046 device;

Table 67. Parameters of individual external dose distribution for a reference sample of population in the investigated region according to the TL-measurements (normalized to ^{137}Cs soil deposition of 1 MBq m^{-2}).

Time	Duration	Geom. mean	Geom. st. dev.	Arithmetic mean ± SE.	St. dev.	Percentiles, mSv			
	months	mSv		mSv	mSv	2.5%	5%	95%	97.5%
December 1986 - December 1987	12	2.23	1.36	2.34 ± 0.17	0.730	1.21	1.34	3.70	4.12
May 1989	1	0.200	1.34	0.208 ± 0.012	0.063	0.111	0.123	0.324	0.359
October 1991	1	0.132	1.44	0.141 ± 0.013	0.053	0.064	0.072	0.241	0.274
November 1992	1	0.094	1.43	0.100 ± 0.006	0.037	0.046	0.052	0.170	0.192

Table 68. Parameters of individual external dose distribution for a reference sample of population in the investigated region according to the TL-measurements.

Time	Duration	Geom. mean	Geom. st. dev.	Arithmetic mean ± SE	St. dev.	Percentiles, mSv			
	months	mSv		mSv	mSv	2.5%	5%	95%	97.5%
December 1986 - December 1987	12	1.59	1.71	1.84 ± 0.19	1.02	0.54	0.66	3.85	4.65
May 1989	1	0.142	1.69	0.163 ± 0.015	0.084	0.050	0.060	0.338	0.406
October 1991	1	0.094	1.77	0.111 ± 0.013	0.069	0.030	0.037	0.241	0.294
November 1992	1	0.067	1.76	0.079 ± 0.007	0.048	0.022	0.026	0.170	0.208

T is the waist length, cm;
P is the device reading of the measurement of the person, μR/hour or pulse/sec;
P_b is the average value of the device background, μR/hour or pulse/sec;
K_s is the shielding factor of the external background by the body of the person (unitless). In the position "standing," K_s is 0.9, and in the position "sitting bending," K_s depends on the body mass:
$K_s = 0.9$ at $m \leq 10$ kg;
$K_s = 0.85$ at 10 kg $< m \leq 30$ kg;
$K_s = 0.8$ at 30 kg $< m \leq 60$ kg;
$K_s = 0.7$ at $m > 60$ kg.

The calibration factors for different devices were obtained by means of measurements of metrologically certified whole body phantoms and of volunteers (Table 69).

Table 69. Calibration factors for whole body counting.

Position of the investigated person	SRP-68-01, μCi/(cm*μR/h)	Robotron with NaI(Tl) 25x25 mm, μCi/(cm*cps)	Robotron with NaI(Tl) 40x40 mm, μCi/(cm*cps)	Robotron with NaI(Tl) 63x63 mm, μCi/(cm*cps)
"Sitting bending"	0.0005	0.0024	0.00058	0.00019
"Standing" or "sitting straight"	0.00125	0.0038	0.0010	0.0003

Since 1992, a whole body counter of the SEG-04T model (Russia) mounted in a mobile radiometric laboratory based on a Mercedes minibus was used for radiometric investigations in the population. The technique of measurements with SEG-04T devices, in the geometry of the armchair, was certified at the Mendeleev Research Institute of Metrology at the stage of producing the devices. The technique was repeatedly calibrated by means of the certified anthropomorphic whole body phantom UF-02T produced in Russia. The design of this polyethylene phantom carrying rod radionuclide sources permits simulation of a human body with a mass from 10 to 110 kg. The devices and techniques used for large-scale whole body measurements of the population permit detection of the cesium radionuclide activity with a measurement error not greater than 30% at the minimum detectable activity of ^{137}Cs, 0.03-0.05 μCi (1100-1850 Bq).

Whole body measurement data

Results of whole-body measurements of ^{137}Cs in men and women are provided in Tables 70-74, for both the controlled and non-controlled (observed) areas. Figs. 7-10 show the dynamics of ^{137}Cs specific activity in the whole body (men and women) of the test area.

Table 70. Specific activity of ^{137}Cs in the whole body of adult men living in the Controlled Area, normalized to ^{137}Cs soil deposition of 1 MBq m^{-2} (Bq kg^{-1} m^2 MBq^{-1}).

Date of measure-ment	Num-ber of persons	Arith. mean	Stand. devia-tion	Stand. error	Percentiles				
					2.5 %	5.0 %	50 %	95 %	97.5 %
01.09.86	1215	2060	2850	82	153	220	1210	6650	9540
15.03.87	45	525	434	65	95	123	404	1330	1710
15.09.87	43	385	317	48	70	90	297	974	1250
15.10.90	34	295	390	67	24	34	179	936	1330
15.09.91	87	198	174	19	33	43	148	518	675
15.03.92	17	175	128	31	38	48	141	416	524
01.06.92	78	102	90	10	17	22	76	267	349
15.09.92	26	307	707	139	8	13	122	1150	1850
15.09.93	37	580	1780	293	8	14	179	2250	3840
15.09.94	35	314	302	51	45	59	226	859	1140
15.09.95	13	292	365	101	26	37	182	903	1270
15.09.96	22	180	159	34	29	38	134	471	615
15.09.97	21	315	196	43	85	104	267	687	840
18.09.98	32	579	530	94	90	118	427	1550	2030

Table 71. Specific activity of ^{137}Cs in the whole body of adult men living in the Observed Area, normalized to ^{137}Cs soil deposition of 1 MBq m^{-2} (Bq kg^{-1} m^2 MBq^{-1}).

Date of meas-urement	Number of persons	Arith. mean	Stand. devia-tion	Stand. error	Percentiles				
					2.5 %	5.0 %	50 %	95 %	97.5 %
01.09.86	762	1850	1640	59	301	393	1380	4860	6350
15.03.87	119	972	499	46	329	390	865	1920	2270
15.09.87	13	1407	845	234	398	483	1210	3010	3660
15.09.97	15	442	465	120	54	74	305	1270	1710
18.09.98	20	1150	1500	335	96	136	702	3630	5140

Table 72. Specific activity of ^{137}Cs in the whole body of adult women living in the Controlled Area, normalized to ^{137}Cs soil deposition of 1 MBq m^{-2} (Bq kg^{-1} m^2 MBq^{-1}).

Date of measurement	Number of persons	Arith. mean	Stand. deviation	Stand. error	Percentiles				
					2.5 %	5.0 %	50 %	95 %	97.5 %
01.09.86	1631	1890	2610	65	141	203	1110	6100	8750
15.03.87	71	445	320	38	99	125	362	1050	1320
15.09.87	46	299	263	39	49	64	225	783	1020
15.10.90	53	201	384	53	8	12	93	720	1110
15.03.91	17	119	125	30	15	20	82	341	460
15.09.91	143	111	107	9	16	21	80	304	404
15.03.92	62	96	82	10	16	21	73	247	321
01.06.92	140	72	57	5	14	18	57	179	228
15.09.93	21	346	667	146	13	20	159	1240	1920
15.09.94	17	199	219	53	22	31	133	582	796
15.09.95	13	158	179	50	17	23	105	469	644
15.09.97	19	135	127	29	20	26	98	366	483
18.09.98	18	350	619	146	16	24	172	1230	1870

Table 73. Specific activity of ^{137}Cs in the whole body of adult women living in the Observed Area, normalized to ^{137}Cs soil deposition of 1 MBq m^{-2} (Bq kg^{-1} m^2 MBq^{-1}).

Date of measurement	Number of persons	Arith. mean	Stand. deviation	Stand. error	Percentiles				
					2.5 %	5.0 %	50 %	95 %	97.5 %
01.09.86	870	1700	1560	53	259	341	1250	4550	5990
15.03.87	159	691	439	35	182	224	584	1520	1870
15.09.87	57	1310	793	105	367	446	1120	2820	3430
15.10.90	46	333	346	51	42	56	231	948	1280
15.09.97	41	209	236	37	23	31	138	618	848
18.09.98	61	851	1150	147	66	94	506	2720	3890

Table 74. Specific activity of ^{137}Cs in the whole body of adult men and women (in total) living in the Controlled Area, normalized to ^{137}Cs soil deposition of 1 MBq m^{-2} (Bq kg^{-1} m^2 MBq^{-1}).

Date of measurement	Number of persons	Arith. mean	Stand. deviation	Stand. Error	Percentiles				
					2.5 %	5.0 %	50 %	95 %	97.5 %
01.06.89	94	149	169	17	16	22	98	441	607
01.06.92	15	91	94	24	11	15	63	259	349
01.06.93	140	208	240	20	21	30	136	621	857
01.06.94	29	160	116	22	35	44	129	378	475

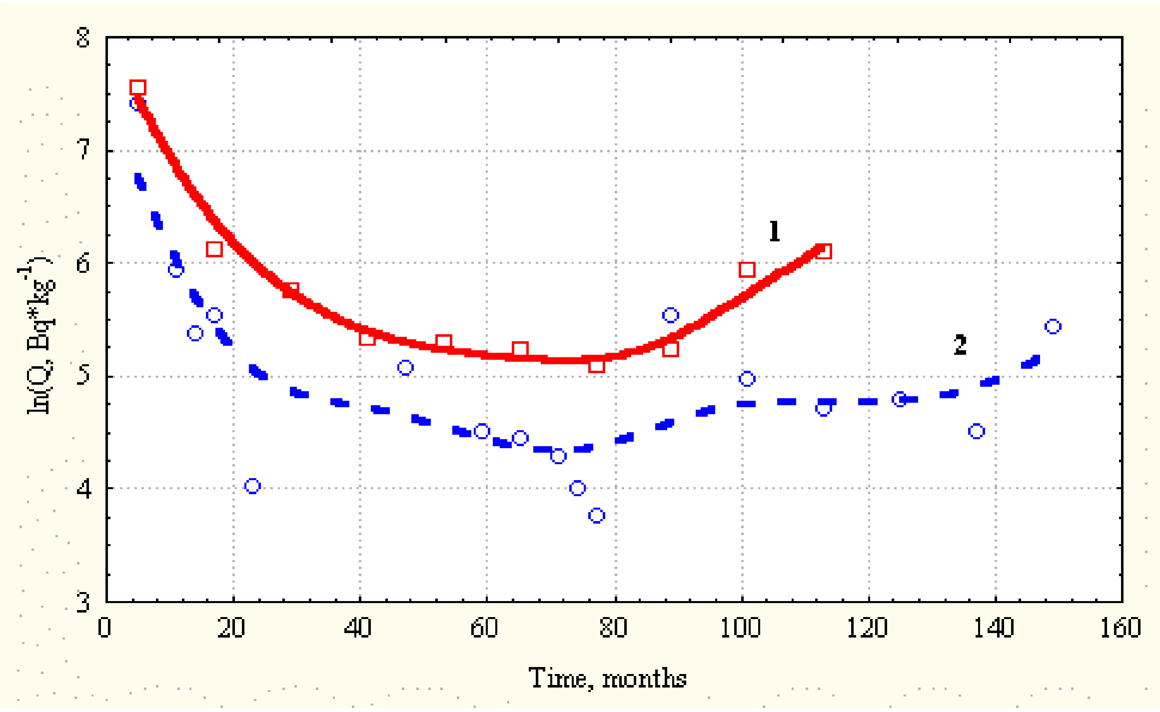

Fig. 7. Mean specific activity of ^{137}Cs in the whole body of adult women living in the Controlled Area (1 - calculated, 2 - WBC measurements).

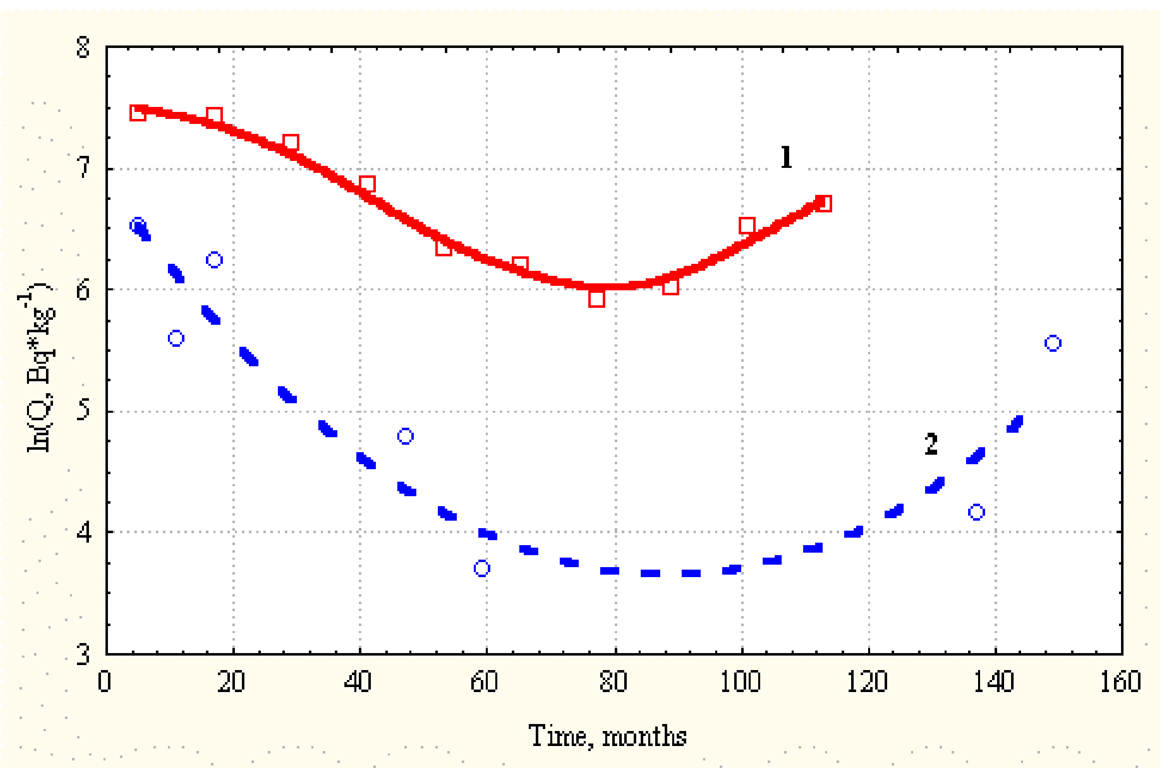

Fig. 8. Mean specific activity of ^{137}Cs in the whole body of adult women living in the Observed Area (1 - calculated, 2 - WBC measurements).

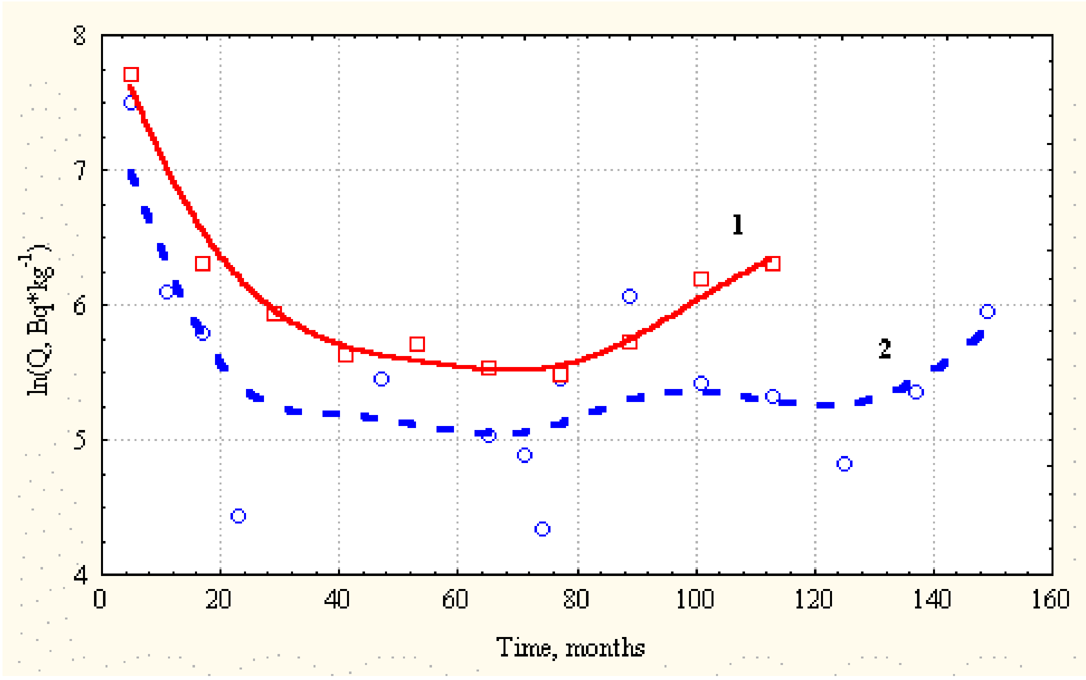

Fig. 9. Mean specific activity of ^{137}Cs in the whole body of adult men living in the Controlled Area (1 - calculated, 2 - WBC measurements).

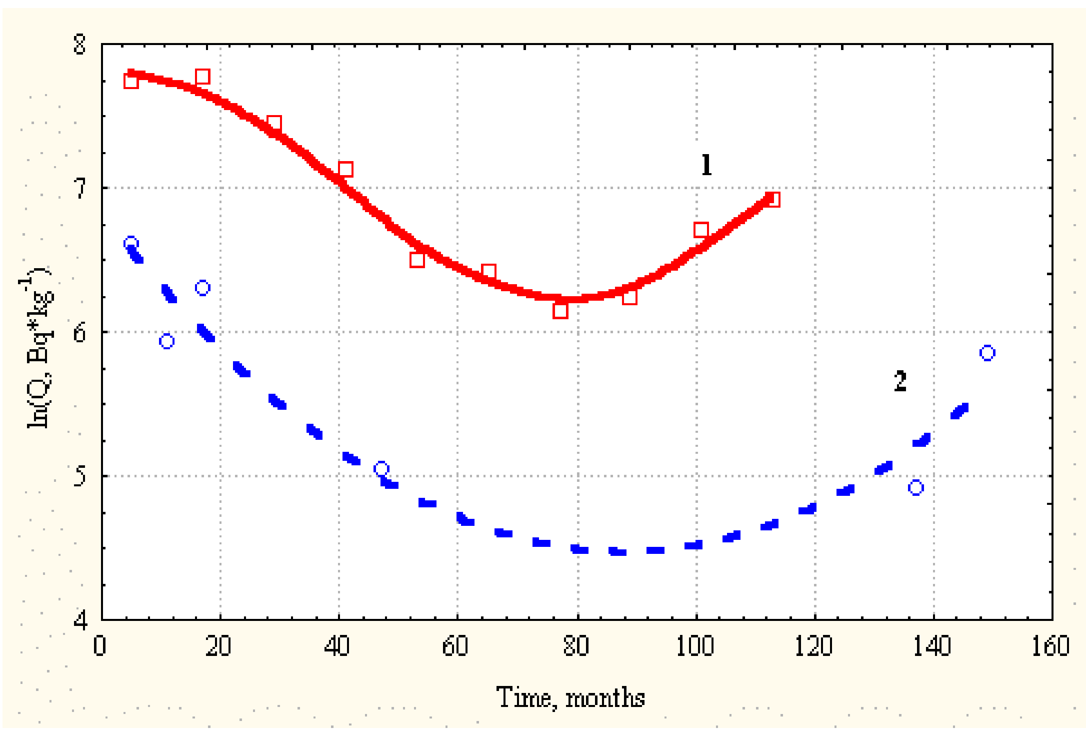

Fig. 10. Mean specific activity of ^{137}Cs in the whole body of adult men living in the Observed Area (1 - calculated, 2 - WBC measurements).

DOSE CALCULATIONS

External Exposure

Ground contamination

For the purpose of external dose assessment, the weighted average density A_{mean}^{137} of soil contamination with ^{137}Cs was calculated for the whole test area, as well as for "Controlled" and "Observed" parts of the test area:

$$A_{mean}^{137} = \frac{\sum_i N_i \cdot A_i^{137}}{\sum_i N_i}, \quad \text{MBq m}^{-2} \qquad (1)$$

where N_i is the number of inhabitants in the i-th settlement; and A_i^{137} is the mean soil contamination density with ^{137}Cs in the i-th settlement, MBq m^{-2}. For the whole test area, A_{mean}^{137} is equal to 0.79 MBq m^{-2} ± 0. 06 MBq m^{-2} (mean ± st. error); for the "Controlled" area, A_{mean}^{137} is equal to 0.87 MBq m^{-2} ± 0. 06 MBq m^{-2} ; for the "Observed" area, A_{mean}^{137} is equal to 0.40 MBq m^{-2} ± 0.04 MBq m^{-2}. To assess the distribution of the individual external doses in a population of 115 settlements of the test area, the distribution of A_{mean}^{137} was considered as a logarithmic one with the geometric mean equal to 0.71 MBq m^{-2} and a geometric standard deviation of 1.55. The appropriate arithmetic mean is 0.79 MBq m^{-2}, with a standard deviation of 0.36 MBq m^{-2}.

External dose model

Cloud exposure

The dose from an external exposure of the *i*-th population group E_i^{cloud} from a radioactive cloud was calculated according to the expression

$$E_i^{cloud} = e_i^{cloud} \cdot (p_i^{out} + f^{cloud} \cdot (1 - p_i^{out})) \cdot \int_{t_0}^{t_e} C^{137}(t) \cdot dt \qquad (2)$$

where e_i^{cloud} = 9.3 x 10^{-11} (mSv m^3 h^{-1} mBq) is the dose factor; p_i^{out} = 0.55 (unitless) is a weighted average according to a composite of the population fraction of daily outdoor residence time during passage of the plume; f^{cloud} = 0.1 (unitless) is a weighted average according to the type of dwellings in the investigated region (value of location factor); and C^{137} = 6 x 10^4 ± 4 x 10^4 (2 st. err.) is the activity concentration (mBq m^{-3}) of ^{137}Cs in outdoor air (it is assumed to be constant during passage of the radioactive cloud).

Ground exposure

The model was developed earlier within the project JSP5 - Pathway Analysis and Dose Distributions (Jacob et al., 1996). The validation of the deterministic model predictions has been described in detail by Golikov et al. (1999). It consists of four sub-models for the following issues:

- absorbed dose rate in air at a reference site in the settlement;
- absorbed dose rate in air at various types of rural or urban locations relative to the reference site;
- occupancy times of different population groups at various types of locations; and
- conversion factor from absorbed dose rate in air to effective dose rate.

The first sub-model calculates the absorbed dose rate $\dot{d}(t)$ in air at a height of 1 m above a virgin plot of soil, normally lawns or meadows (reference site). A plane source below a soil slab with a mass per unit area of 0.5 g cm^{-2} has been chosen as a reference distribution to approximate the energy and angular distribution of the radiation field in air over an undisturbed field during the first year after the deposition for wet deposition as occurred in the studied areas of Russia. The photon field in the model must approximate the real situation because the conversion factors k_i of the absorbed dose rate in air to the effective dose rate in sub-model 2 depend on these parameters.

Absorbed dose rates in air at rural or urban locations of type *j* are expressed by location factors f_j, defined as the ratio of the absorbed dose rate at such locations in a settlement to the absorbed dose rate above the reference site (Meckbach and Jacob, 1998).

The behaviour of man in the radiation field is described by means of occupancy factors p_{ij}, which are the fraction of time spent by representatives of the *i*-th population group at locations of type *j* in the settlement. The type of house where the people live (one-storey wooden or one-storey brick) is an additional parameter.

According to the model, the effective dose rate of representatives of the *i*-th population group $\dot{E}_i(t)$ due to external exposure from deposited ^{137}Cs can be written in the following way:

$$\dot{E}_i(t) = \dot{d}(t) \cdot k_i \cdot \sum_j f_j \cdot p_{ij} \qquad (3)$$

$$\dot{d}(t) = r(t) \cdot A^{137} \cdot \dot{d}_s \cdot \exp(-\lambda^{137} \cdot t) \qquad (4)$$

where A^{137} is the activity per unit area of ^{137}Cs on a reference site at the time radioactive deposition ends; accordingly, $\dot{d}_s$ is the gamma dose rate in air per activity per unit area with a reference distribution of ^{137}Cs in the ground, and λ^{137} is the decay constant of ^{137}Cs. The function *r(t)* is the gamma dose rate in air at the reference site divided by the gamma dose rate in air for the reference distribution. Results of more than 300 measurements performed in the period 1986 to 1995 at sites with distances in the range of 100 to 1000 km from the Chernobyl reactor plant were fitted in the form:

$$r(t) = p_1 \cdot \exp\left(-\frac{\ln 2}{T_1} \cdot t\right) + p_2 \cdot \exp\left(-\frac{\ln 2}{T_2} \cdot t\right) \qquad (5)$$

The resulting parameter values were $p_1 = 0.60$, $p_2 = 0.63$, $T_1 = 1.5$ years, and $T_2 = 50$ years (Golikov et al., 1999). The effective dose of external exposure accumulated during any time interval is determined by integration of the effective dose rate $\dot{E}_i(t)$ over the time of interest.

Numeric values for the model parameters given below have been derived mainly from measurements in the investigated region, located at a distance of 150 to 300 km from the Chernobyl NPP in the north-east part of the Chernobyl trace and subjected to the main radioactive contamination during the period from 28 April to 1 May 1986. Mean values of conversion factors k_i which convert the gamma dose rate in air to the effective dose rate in a member of the population of (age) group *i* were obtained for the three groups of the population using results of phantom experiments (Jacob et al., 1996) and Monte-Carlo calculations (Jacob et al., 1990). For adults, the conversion factor is 0.75 Sv Gy^{-1}. Seasonal average values of occupancy factors for three groups of the rural population, their main statistical parameters, and values for annual occupancy factors were given earlier. The values of location factors were assumed to be time-dependent according to the expression

$$_{j,Cs}(t) = a_1 \cdot \exp(-\ln 2 \cdot t/T) + a_2 \qquad (6)$$

where *t* is the time elapsed since the moment of the accident (years), and a_1, T, and a_2 are the parameters. The values of parameters a_1, T, and a_2 for different locations are given in Table 75.

Table 75. Values of parameters in expression (6).

Type of location (j)	a_1, unitless	a_2, unitless	T, years
Living area (indoors)			
1 st. wooden house	0.07	0.13	1.7
1 st. brick house	0.05	0.07	1.7
multi-storey house	0.01	0.02	1.7
Living area (outdoors)	0.25	0.55	1.7
Work area (indoors)	0.05	0.07	1.7
Work area (outdoors)	0.37	0.33	1.7
Ploughed field	0	0.5	-
Virgin land	0	1	-
Rest area	0	1	-

The statistical characteristics of the model parameters for rural environments were calculated on the basis of measurement data in different locations in a settlement and its vicinity (Golikov et al., 1999).

For the attenuation function *r(t)*, it is proposed to use a lognormal distribution for each year with geometric means as calculated according to formula (5) and a time-independent value of the geometric standard deviation, which is 1.2.

For the location factors, it is proposed to use a lognormal distribution with geometric means as calculated according to formula (6) and time-independent values of the geometric standard deviations. On the basis of the available data, the following geometric standard deviations were derived: outdoor, 1.4; 1-storey wooden/brick, 1.5; ploughed, 1.2; virgin, 1.0 [the distribution is taken into account in the attenuation function *r(t)*]. Location factors are obtained by dividing the gamma-dose rate at a given location by the gamma-dose rate above a reference site with the average ^{137}Cs activity per unit area in the settlement. Due to this construction, the variability of the location factors contains the variability of ^{137}Cs activity per unit area in the settlement. Accordingly, the model will express the full variability of gamma-dose rates in air at the various locations by calculating with average values for the ^{137}Cs activity per unit area in the settlement and distributions for the location factors.

The values of the conversion factors k_i which convert the gamma dose rate in air to the effective dose rate in a member of population (age) group *i* are assumed here to be normally distributed with a mean value of 0.75 Sv Gy^{-1} for adults and a relative standard deviation of 0.05.

Results of model predictions

Table 76 gives the calculated distributions of individual external doses for the adult population of the study area.

Table 76. Parameters of the individual external dose distributions for the adult population of the study area, according to the model prediction.

Time period	Geom. Mean, mSv	Geom. st. dev.	Arithm. Mean, mSv	St. dev., mSv	Percentiles, mSv			
GROUND EXPOSURE					2.5%	5%	95%	97.5%
28 April 1986-30 April 1987	3.06	1.64	3.46	1.82	1.14	1.35	6.92	8.23
28 April 1986-31 December 1990	10.0	1.73	11.6	6.86	3.33	4.03	24.6	29.8
28 April 1986-31 December 1995	15.2	1.70	17.5	9.88	5.26	6.34	36.5	44.0
28 April 1986-31 December 2036	33.6	1.67	38.3	21.0	12.0	14.4	78.2	93.7

Internal Exposure

Internal dose model (ingestion)

Internal doses in the population are determined by the intake of ^{137}Cs into the body of inhabitants, mainly with food (especially with milk, meat, potatoes and forest mushrooms). The average effective internal dose to inhabitants in a settlement from ^{137}Cs radiation attributed to its intake with food during the time period Δt (days) is determined on the basis of the data about the ^{137}Cs content in local agricultural and natural food products and about typical food rations of the population during the same time period. The internal effective dose (E_{int}, mSv) was calculated with the formula

$$E_{int} = dk_{137} \cdot I \cdot \Delta t \qquad (7)$$

where $dk_{137} = 1.3 \times 10^{-5}$ mSv Bq^{-1} is the dose factor for intake of ^{137}Cs in food in the body of adults, according to ICRP Publication 67; and I, Bq day^{-1}, is the average *daily* intake of ^{137}Cs in the body of adult inhabitants of the settlement during the time period Δt.

The average daily intake (I, Bq day^{-1}) of ^{137}Cs in the body of adult inhabitants of a settlement was determined with the formula:

$$I = V_m \cdot C_m + V_p \cdot C_p + V_{pot} \cdot C_{pot} + 0.5 \cdot V_{mush} \cdot C_{mush} \quad (8)$$

where: V_m, V_p, V_{pot}, V_{mush}, kg (or L) day^{-1}, is the average daily consumption of milk, meat (pork, because the rural population in the test region consumes mainly pork), potatoes and mushrooms, respectively; C_m, C_p, C_{pot}, C_{mush}, Bq/kg (or L), is the average ^{137}Cs concentration or specific activity in milk, pork, potatoes and mushrooms of local origin, respectively; and 0.5, (unitless), is the average factor of ^{137}Cs losses after culinary processing of fresh mushrooms.

The dose predicted from 1995 until 2036 was calculated on the basis of the starting data of 1995, assuming that the decontamination half-period of the main food products from ^{137}Cs is 10 years.

Effectiveness of dietary changes in reduction of the internal dose

Available data on human diets in the test area before and after the Chernobyl accident permit the estimation of the effectiveness of internal (ingestion) dose reduction based on changes in the diet. In this case the effectiveness factor F is defined as ratio of a mean ingestion dose E_{ing0} estimated from the intake with an undisturbed food ration to the mean ingestion dose E_{ing} estimated from the intake with the food ration changed in order to reduce internal exposure:

$$F = E_{ing0} / E_{ing}, \text{ rel. units.} \quad (9)$$

The effectiveness factor F was calculated according to formula (9) for adults of both genders living in two areas under consideration (Controlled and Observed areas), and for different time periods after the radioactive contamination of the test area due to the Chernobyl accident. Tables 77-80 present mean values of the effectiveness factor F where E_{ing0} are hypothetical mean ingestion doses, calculated with an undisturbed food ration, and E_{ing} are ingestion doses calculated with the food ration changed for protection purposes.

It should be noted that values of the factor F do not reflect the effectiveness of agricultural countermeasures applied, because the Iput Scenario does not contain separate data sets on ^{137}Cs concentrations in food produced with and without application of agricultural countermeasures. As expected, the effectiveness of population protection from internal exposure was higher in the "Controlled area," where F is 2.3-2.4 during the first year after area contamination and 3.8-4.6 in subsequent periods, against 1.5-2.0 in the "Observed area" during the whole decade 1986-1995.

Table 77. Effectiveness factor F resulting from dietary changes for women in the "Controlled area".

Time period	Mean dose, mSv		Effectiveness factor
	E_{ing0}[a]	E_{ing}[b]	F, rel. units
27 April 1986- 30 April 1987	10.19	4.44	2.3
27 April 1986- 31 December 1990	29.01	6.29	4.6
27 April 1986- 31 December 1995	37.17	8.89	4.2

[a] without dietary changes.
[b] with dietary changes.

Table 78. Effectiveness factor F resulting from dietary changes for women in the "Observed area".

Time period	Mean dose, mSv		
	E_{ing0}	E_{ing}	F, rel. units
27 April 1986- 30 April 1987	9.48	5.67	1.7
27 April 1986- 31 December 1990	27.03	13.84	2.0
27 April 1986- 31 December 1995	34.80	19.64	1.8

Table 79. Effectiveness factor F resulting from dietary changes for men in the "Controlled area".

Time period	Mean dose, mSv		
	E_{ing0}	E_{ing}	F, rel. units
27 April 1986- 30 April 1987	12.65	5.31	2.4
27 April 1986- 31 December 1990	34.12	7.88	4.3
27 April 1986- 31 December 1995	44.05	11.57	3.8

Table 80. Effectiveness factor F resulting from dietary changes for men in the "Observed area".

Time period	Mean dose, mSv		
	E_{ing0}	E_{ing}	F, rel. units
27 April 1986- 30 April 1987	11.60	7.56	1.5
27 April 1986- 31 December 1990	31.76	18.73	1.7
27 April 1986- 31 December 1995	41.26	25.99	1.6

Internal dose model (inhalation)

Inhalation dose from the radioactive cloud

We assessed the internal dose due to ^{137}Cs inhalation during the passage of the radioactive cloud with the formula

$$E_i = C \cdot V \cdot \Delta T \cdot K \cdot d^{inh} \quad (10)$$

where C is the average concentration of ^{137}Cs in the above-ground layer of air at the cloud passage (60 ± 40 Bq m^{-3}); V is the daily volume of inhaled air of an adult person (22.2 m^3 d^{-1}); ΔT is the time of the cloud passage (3 days); and K is the factor that takes into account the relative time of staying outdoors and indoors for a rural inhabitant, for which it is assumed that C is reduced twice indoors as compared with the same value outdoors, $K = 0.45 + (0.55 \times 0.5) = 0.725$ (unitless). The numeric value of the dose factor d^{inh} for adult inhabitants was assumed to be equal to 4.6×10^{-6} mSv Bq^{-1}.

Inhalation dose from resuspension

To assess the inhalation intake of ^{137}Cs in the body of inhabitants, regular information about the concentration in the above-ground layer of atmospheric air within the settlement and its vicinity is necessary. In the absence of such data, the ^{137}Cs concentration in the air is assessed by multiplication of the resuspension factor (wind rise), W, by the average surface activity of the ^{137}Cs on soil, A^{137}, in the settlement and its vicinity. The average annual intake of ^{137}Cs in the body with inhaled air (inhalation intake), I^{inh}, is assessed with the formula

$$I^{inh} = V_i \times W \times A^{137} \text{ kBq year}^{-1} \quad (11)$$

where V_i (m^3 a^{-1}) is the annual inhaled volume; W (m^{-1}) is the resuspension factor; and A^{137} (kBq m^{-2}) is the average surface activity of ^{137}Cs on soil in the settlement and its vicinity.

According to data from multiple observations in the zone of radiation accidents, the resuspension factor decreases with time and strongly depends on social and natural conditions. In 1989-1990, the resuspension factors were assessed at the following values: in settlements, 10^{-9} m^{-1}; at work outdoors, 10^{-8} m^{-1}; and at dust-forming operations, up to 10^{-7} - 10^{-6} m^{-1}. Taking into consideration the occupation of a considerable portion of the rural inhabitants in outdoor work, and taking into account the seasonal character of this work, we assumed an average annual value for the resuspension factor W for the entire population of rural settlements to be equal to 3.3×10^{-9} m^{-1} ($0.84 \times 10^{-9} + 0.15 \times 10^{-8} + 0.01 \times 10^{-7}$), where 0.84, 0.15, and 0.01 are the fractions of time during a year for rural inhabitants to stay in the settlements proper, to work outdoors during the summer period, and to work at dust-forming operations during the summer period, respectively.

The results closest to these values (for rural settlements) are obtained when the Linsley calculation model is used (Linsley, 1978). We applied this model to assess ^{137}Cs inhalation intake in the body of inhabitants due to resuspension. This model gives the following regularity for variation of the resuspension factor directly in the settlements:

$$W(t) = 10^{-6}\exp(-3.65t) + 10^{-9}, \text{ m}^{-1} \quad (12)$$

where t is the time elapsed after the accident in years.

Taking into account the occupations of the rural population at different jobs, including dust-forming ones, we assumed

$$W(t) = 3.3 \times 10^{-6} \exp(-3.65t) + 3.3 \times 10^{-9},\ m^{-1} \qquad (13)$$

The annual inhaled volume for adults, V_i, was assumed to be equal to 8.1×10^3 m^3 a^{-1}.

The average annual effective dose from ^{137}Cs, E_{jnh}, was calculated with the formula

$$E_{jnh} = d^{inh} \times I^{inh}, \qquad mSv\ a^{-1} \qquad (14)$$

The numeric value of the dose factor d^{inh} for adult inhabitants was assumed to be equal to 4.6×10^{-6} mSv Bq^{-1}.

<u>Calculation of the average ^{137}Cs content in the body of inhabitants based on data on radionuclide intake</u>

In the general form, the formula for calculation of the expected average content of ^{137}Cs in the body of inhabitants is the following:

$$\overline{Q}^{1}_{137} = \int_0^{t_1} I_{137}(\tau) \cdot R(t_1 - \tau) d\tau,\ \ Bq \qquad (15)$$

where R(t) = 0.9·exp(-ln2·t/90), unitless, is the retention function for ^{137}Cs in the body of adult persons of both sexes; the ^{137}Cs excretion half-period from the body of an adult person is assumed to be equal to 90 days (according to our data); and $I_{137}(\tau)$, Bq d^{-1}, is the average *daily* intake of cesium-137 in the body of adult inhabitants of the settlement. This formula was used for determination of the radionuclide content in the body of inhabitants as of September 1986 (t_1 = 120 days).

In the rest of the cases, we assumed that ^{137}Cs intake was chronic, and the calculation was performed according to the formula:

$$(Q/M)_{av} = 1.67 * I_{137}(\tau), \quad Bq \cdot kg^{-1} \qquad (16)$$

In the absence of specific data, we assumed that M = 70 kg.

Total Dose

Total dose model

The total effective dose for an average adult living in the test region, I, is the sum of the doses from inhalation, ingestion and external radiation. The internal dose (ingestion) was based on the dietary intake. The inhalation dose was calculated separately to show its low contribution to the internal dose. The internal dose was given as a committed effective dose. The 95% confidence interval of the total dose was calculated on the basis of the values of the standard errors of its components:

$$95\%\ Conf.Int. = (\bar{E}_{ext} + \bar{E}_{int}) \pm 1.96 \cdot \sqrt{(st.err.)^2_{ext} + (st.err.)^2_{int}} \qquad (17)$$

SUMMARY OF TEST DATA AND DOSE ESTIMATES

The following measurements of agricultural products and nonagricultural food items are provided for use as test data: annual average concentrations in leafy vegetables (Table 81), hay (Table 82), potatoes (Table 83), and cereals (Table 84); monthly or quarterly average concentrations in milk (Table 85), beef (Table 86), and pork (Table 87); and annual average concentrations in edible mushrooms (Tables 88-89), wild berries (Tables 90-91), and freshwater fish (Tables 92-93).

Estimates of daily intake by humans based on measurements are provided in Tables 94-97, and estimates of the average concentrations in the whole body of humans (men and women) as calculated from estimated intakes are provided in Tables 98-101. Measured average concentrations in the whole body of humans (men and women) and distributions of whole body concentrations are provided in Tables 102-106.

Estimates of external dose based on measurements are provided in Table 107. Distributions of measured individual external doses for reference samples of the population are provided in Tables 108-109. Dose estimates based on measurements are also provided for inhalation dose (Table 110), ingestion dose (Tables 111-114), and total dose from all pathways (Tables 115-118). Tables 111-114 also indicate the three principal foods contributing to each dose estimate.

Table 81. ^{137}Cs concentrations in leafy vegetables.

Time period	Mean (Bq kg^{-1} f.w.)	95% confidence interval Lower bound	Upper bound	Number of Samples
1986	607	466	748	68
1987	270	194	346	30
1988	170	113	227	28
1989	179	140	217	25
1990	117	87	148	58
1991	70	56	84	49
1992	58	48	68	44
1993	45	35	54	45
1994	31	24	38	36
1995	66	45	88	48
1996	55	46	64	53

Table 82. ^{137}Cs concentrations in hay.

Time period	Mean (Bq kg^{-1})	95% confidence interval Lower bound	Upper bound	Number of Samples
1986	34627	27002	42252	134
1987	16238	14002	18473	134
1988	16715	9838	23592	67
1989	8761	7279	10243	71
1990	10140	6367	13120	74
1991	3130	2714	3547	104
1992	2290	1892	2689	154
1993	1110	979	1241	208
1994	2991	2364	3618	208
1995	3375	2822	3927	208
1996	2260	1996	2524	168

Table 83. ^{137}Cs concentrations in potatoes.

Time period	Mean (Bq kg^{-1} f.w.)	95% confidence interval Lower bound	Upper bound	Number of Samples
1986	256	187	326	108
1987	156	127	185	64
1988	119	99	140	74
1989	98	69	126	56
1990	93	73	114	98
1991	75	66	84	114
1992	73	48	97	89
1993	34	28	39	97
1994	29	26	32	108
1995	51	39	63	67
1996	40	32	47	53

Table 84. ^{137}Cs concentrations in grain of cereals, dry weight.

Time period	Mean (Bq kg^{-1} d.w.)	95% confidence interval Lower bound	Upper bound	Number of Samples
1986	670	568	772	161
1987	468	331	605	24
1988	434	208	660	24
1989	195	131	260	56
1990	82	50	115	123
1991	39	32	45	133
1992	33	30	37	198
1993	25	20	31	157
1994	38	33	42	258
1995	63	57	68	324
1996	56	47	64	313

Table 85. ^{137}Cs concentrations in milk.

Time period	Mean (Bq L^{-1})	95% confidence interval Lower bound	Upper bound	Number of Samples
1986, May	9609	7377	11841	57
1986, June	4438	3577	5298	68
1986, July	2968	2093	3844	73
1986, August	2544	1835	3252	184
1986, September	1961	1530	2391	166
1986, IV	1063	830	1296	94
1987, I	1183	903	1464	87
1987, II	1854	1563	2145	183
1987, III	1935	1539	2332	134
1987, IV	615	412	818	79
1988, I	623	541	706	148
1988, II	1762	1339	2185	62
1988, III	2016	1458	2575	81
1988, IV	730	557	903	143
1989, I	636	550	721	218
1989, II	1089	888	1290	176
1989, III	1610	1265	1955	188
1989, IV	403	360	446	206
1990, I	330	284	377	213
1990, II	428	362	494	240
1990, III	351	309	393	197
1990, IV	115	103	128	148
1991, I	125	109	141	193
1991, II	406	334	478	159
1991, III	449	348	550	174
1991, IV	122	107	137	193
1992, I	156	136	176	209
1992, II	215	174	256	254
1992, III	285	235	335	301
1992, IV	118	101	135	254
1993, I	136	117	155	182
1993, II	176	153	198	285
1993, III	159	141	177	297
1993, IV	122	98	146	184
1994, I	116	95	137	172
1994, II	311	265	357	312
1994, III	388	326	451	340
1994, IV	181	156	206	235
1995, I	156	129	182	196
1995, II	237	207	268	294
1995, III	489	367	610	306
1995, IV	140	123	157	216
1996, I	161	136	186	115
1996, II	228	192	264	220
1996, III	450	275	625	102
1996, IV	146	107	185	120

Table 86. ^{137}Cs concentrations in beef.

Time period	Mean ($Bq\ kg^{-1}$ f.w.)	95% confidence interval Lower bound	Upper bound	Number of Samples
1986, May	6073	2449	9697	13
1986, June	7615	5673	9556	28
1986, July	8224	5065	11382	22
1986, August	4626	3076	6176	18
1986, September	5960	2524	9395	27
1986, IV	2908	2035	3781	41
1987, I	3334	2078	4591	12
1987, II	3653	2439	4867	34
1987, III	3654	2270	5038	28
1987, IV	1906	1254	2558	31
1988, I	1183	903	1464	87
1988, II	3079	2217	3941	57
1988, III	5256	3408	7105	79
1988, IV	1994	1605	2383	64
1989, I	1831	1338	2323	85
1989, II	3066	2165	3966	87
1989, III	3303	2399	4208	111
1989, IV	896	753	1038	86
1990, I	908	758	1058	73
1990, II	1328	984	1672	49
1990, III	2128	1732	2524	143
1990, IV	565	432	699	54
1991, I	464	356	572	36
1991, II	1001	649	1354	51
1991, III	957	723	1191	49
1991, IV	348	281	414	61
1992, I	393	307	479	58
1992, II	876	515	1238	72
1992, III	869	634	1104	81
1992, IV	509	310	708	29
1993, I	540	336	743	31
1993, II	606	322	890	28
1993, III	858	527	1188	31
1993, IV	437	328	546	26
1994, I	450	318	582	49
1994, II	600	427	774	43
1994, III	555	423	687	43
1994, IV	521	275	767	21
1995, I	526	325	727	39
1995, II	532	356	708	42
1995, III	518	399	637	46
1995, IV	477	244	710	19
1996, I	497	379	615	56
1996, II	351	309	393	197
1996, III	462	376	547	88
1996, IV	471	448	493	92

Table 87. ^{137}Cs concentrations in pork.

Time period	Mean (Bq kg^{-1} f.w.)	95% confidence interval Lower bound	Upper bound	Number of Samples
1986, May	1325	815	1836	17
1986, June	4088	2556	5620	32
1986, July	3385	2151	4618	19
1986, August	3140	2407	3873	27
1986, September	1995	1518	2472	41
1986, IV	1508	927	2089	63
1987, I	1223	696	1750	54
1987, II	2340	1954	2726	87
1987, III	2879	1916	3841	56
1987, IV	1041	656	1425	71
1988, I	1002	786	1217	62
1988, II	1820	1417	2224	83
1988, III	3145	1707	4583	97
1988, IV	981	810	1152	78
1989, I	966	807	1124	94
1989, II	1787	1027	2547	87
1989, III	1308	1096	1519	102
1989, IV	521	402	640	94
1990, I	675	441	909	81
1990, II	922	743	1101	89
1990, III	1452	1077	1827	99
1990, IV	503	274	731	97
1991, I	311	243	379	54
1991, II	765	505	1025	101
1991, III	1284	862	1705	112
1991, IV	253	199	307	49
1992, I	410	277	543	36
1992, II	323	211	434	53
1992, III	352	322	383	58
1992, IV	124	94	155	51
1993, I	125	95	154	47
1993, II	133	81	186	14
1993, III	252	111	394	36
1993, IV	110	74	145	42
1994, I	173	114	233	27
1994, II	164	101	227	44
1994, III	224	160	288	52
1994, IV	151	124	177	67
1995, I	133	99	167	44
1995, II	166	110	223	46
1995, III	201	152	250	49
1995, IV	229	137	321	27
1996, I	216	134	297	54
1996, II	179	146	211	99
1996, III	192	154	230	145
1996, IV	150	100	199	87

Table 88. ^{137}Cs concentration in forest, edible mushrooms (mixed samples).

Time period	Mean (kBq kg^{-1} f.w.)	95% confidence interval Lower bound	Upper bound
1986	11.2	7.6	14.8
1987	17.9	5.4	30.4
1988	12.0	5.7	18.3
1989	10.1	-	29.7
1990	13.4	5.8	21.0
1991	5.9	-	14.3
1992	7.0	4.2	9.7
1994	15.6	5.2	26.0
1995	15.3	2.3	28.3
1996	14.5	1.6	27.4

Table 89. Specific activity of ^{137}Cs in forest mushrooms (mixed samples, Bq kg^{-1} f.w.).

Year	Number of samples	Mean	Stand. deviation	Stand. error	Percentiles				
					2.5%	5.0%	50%	95%	97.5%
1986	198	11200	25700	1820	302	484	4510	42000	67300
1987	83	17900	57000	6260	241	415	5370	69600	120000
1988	99	12000	31200	3140	248	407	4320	45800	75500
1989	42	10100	63300	9800	34	68	1610	38200	74800
1990	163	13400	48400	3790	139	245	3580	52300	92800
1991	27	5950	21800	4200	59	106	1570	23200	41100
1992	77	6960	11900	1360	337	508	3500	24200	36500
1994	164	15600	66300	5180	116	211	3580	60800	111000
1995	261	15300	105000	6510	42	85	2190	56600	113000
1996	230	14500	98000	6460	42	84	2130	54000	107000

Table 90. ^{137}Cs concentrations in wild berries.

Time period	Mean (kBq kg^{-1} f.w.)	95% confidence interval Lower bound	Upper bound
1986	8.0	3.0	14.0
1987	4.0	1.2	7.0
1988	3.5	1.0	5.0
1989	2.6	0.9	4.3
1990	2.4	0.9	4.0
1991	2.3	0.8	4.0
1993	6.8	-	14.0
1995	2.1	-	7.1
1996	5.5	-	21.4

Table 91. Specific activity of ^{137}Cs in forest berries (mixed samples, Bq kg^{-1} f.w.).

Year	Number of samples	Mean	Stand. deviation	Stand. error	Percentiles				
					2.5%	5.0%	50%	95%	97.5%
1993	60	6800	28000	3620	54	97	1600	26500	48100
1995	61	2150	19400	2490	4	7	237	7600	15800
1996	46	5490	53900	7940	8	16	556	19000	40100

Table 92. ^{137}Cs concentrations in river fish.

Time period	Mean (kBq kg^{-1} f.w.)	95% confidence interval Lower bound	Upper bound	Number of Samples
1986	2.0	0.8	3.4	6
1987	2.4	1.0	4.0	8
1988	1.4	0.6	2.2	6
1989	0.6	0.24	1.0	6
1990	0.58	0.2	1.0	14
1991	0.25	0.1	0.4	20
1992	0.25	0.06	0.42	20
1993	0.20	0.06	0.34	8
1994	0.17	0.05	0.30	4
1995	0.15	0.05	0.25	3
1996	0.15	0.10	0.20	23

Table 93. ^{137}Cs concentrations in lake fish.

Time period	Mean (kBq kg^{-1} f.w.)	95% confidence interval Lower bound	Upper bound	Number of Samples
1986	36	7	65	11
1987	42	9	75	10
1988	28	5	50	8
1989	16	3	30	6
1990	10	6	14	18
1991	12	7	18	30
1992	11	7	15	15
1993	10	7	13	24
1994	6.7	4.7	8.7	15
1995	4.0	1.0	7.0	4
1996	3.0	0.5	5.5	6

Table 94. Authors' estimates of average human ^{137}Cs intake (Controlled Area, women).

Time	Mean	95% confidence interval	
	Bq d^{-1}	Lower bound	Upper bound
June 1986	2181	1681	2681
IV 1986	217	144	291
II 1987	251	176	327
IV 1987	198	126	270
II 1988	186	140	232
IV 1988	137	95	178
II 1989	139	46	232
IV 1989	106	14	198
II 1990	111	67	156
IV 1990	105	60	149
II 1991	94	52	136
IV 1991	74	33	115
II 1992	93	70	116
IV 1992	80	59	101
II 1993	103	47	159
IV 1993	95	40	149
II 1994	199	129	268
IV 1994	159	95	224
II 1995	191	115	268
IV 1995	170	90	250

Table 95. Authors' estimates of average human ^{137}Cs intake (Non-controlled Area, women).

Time	Mean	95% confidence interval	
	$Bq\ d^{-1}$	Lower bound	Upper bound
June 1986	2010	1559	2461
IV 1986	710	516	904
II 1987	940	720	1161
IV 1987	552	373	732
II 1988	789	625	952
IV 1988	420	321	520
II 1989	510	254	766
IV 1989	291	42	540
II 1990	328	220	436
IV 1990	257	151	363
II 1991	257	147	368
IV 1991	160	52	267
II 1992	205	160	250
IV 1992	166	122	209
II 1993	244	103	385
IV 1993	220	80	361
II 1994	371	227	516
IV 1994	300	159	441
II 1995	362	189	536
IV 1995	319	146	491

Table 96. Authors' estimates of average human ^{137}Cs intake (Controlled Area, men).

Time	Mean	95% confidence interval	
	Bq d^{-1}	Lower bound	Upper bound
June 1986	2546	1875	3216
IV 1986	292	159	425
II 1987	312	179	446
IV 1987	276	143	409
II 1988	224	149	299
IV 1988	190	117	264
II 1989	175	0	356
IV 1989	154	0	335
II 1990	176	92	261
IV 1990	172	88	257
II 1991	132	52	212
IV 1991	112	33	192
II 1992	138	98	177
IV 1992	123	86	161
II 1993	170	62	278
IV 1993	160	53	266
II 1994	265	151	379
IV 1994	232	121	343
II 1995	263	131	396
IV 1995	250	118	382

Table 97. Authors' estimates of average human ^{137}Cs intake (Non-controlled Area, men).

Time	Mean	95% confidence interval	
	Bq d^{-1}	Lower bound	Upper bound
June 1986	2603	2011	3194
IV 1986	944	677	1212
II 1987	1324	1020	1629
IV 1987	736	488	984
II 1988	1035	774	1296
IV 1988	536	380	691
II 1989	649	283	1015
IV 1989	370	29	712
II 1990	396	241	551
IV 1990	315	166	464
II 1991	314	160	469
IV 1991	199	52	347
II 1992	262	196	328
IV 1992	220	158	283
II 1993	296	101	491
IV 1993	273	80	467
II 1994	454	251	656
IV 1994	393	195	591
II 1995	461	220	702
IV 1995	416	177	655

Table 98. ^{137}Cs concentration in whole body (Controlled Area, women), as calculated from intake.

Time	Mean	95% confidence interval	
	Bq kg^{-1}	Lower bound	Upper bound
30 September 1986	1906	1268	2544
30 September 1987	454	320	588
30 September 1988	320	236	404
30 September 1989	210	56	364
30 September 1990	199	124	274
30 September 1991	190	118	262
30 September 1992	164	124	204
30 September 1993	187	93	280
30 September 1994	378	249	506
30 September 1995	445	301	590

Table 99. ^{137}Cs concentration in whole body (Non-controlled Area, women), as calculated from intake.

Time	Mean	95% confidence interval	
	$Bq\ kg^{-1}$	Lower bound	Upper bound
30 September 1986	1782	1229	2336
30 September 1987	1699	1309	2089
30 September 1988	1355	1091	1619
30 September 1989	956	522	1389
30 September 1990	576	395	758
30 September 1991	494	308	681
30 September 1992	373	296	449
30 September 1993	417	182	652
30 September 1994	685	441	928
30 September 1995	825	526	1125

Table 100. ^{137}Cs concentration in whole body (Controlled Area, men), as calculated from intake.

Time	Mean	95% confidence interval	
	$Bq\ kg^{-1}$	Lower bound	Upper bound
30 September 1986	2239	1448	3029
30 September 1987	544	319	768
30 September 1988	377	252	502
30 September 1989	277	0	578
30 September 1990	301	160	443
30 September 1991	253	119	387
30 September 1992	239	171	307
30 September 1993	308	129	487
30 September 1994	488	294	681
30 September 1995	547	314	779

Table 101. ^{137}Cs concentration in whole body (Non-controlled Area, men), as calculated from intake.

Time	Mean Bq kg^{-1}	95% confidence interval Lower bound	 Upper bound
30 September 1986	2307	1600	3015
30 September 1987	2389	1848	2930
30 September 1988	1731	1235	2227
30 September 1989	1252	615	1889
30 September 1990	670	414	926
30 September 1991	610	350	871
30 September 1992	469	354	583
30 September 1993	511	187	834
30 September 1994	826	483	1169
30 September 1995	1013	590	1436

Table 102. Distribution of ^{137}Cs in the whole body of adult men living in the Controlled Area.*

Date of measurement	Number of people	Mean (Bq kg^{-1})	Standard deviation	Standard error	Percentiles				
					2.5%	5.0%	50%	95%	97.5%
01.09.86	1215	1790	2480	71.3	133	191	1050	5790	8300
15.03.87	45	457	378	56.6	82.7	107	351	1160	1490
15.09.87	43	335	276	41.8	60.9	78.3	258	847	1090
15.10.90	34	257	339	58.3	20.9	29.6	156	814	1160
15.09.91	87	172	151	16.5	28.7	37.4	129	451	587
15.03.92	17	152	111	27.0	33.1	41.8	123	362	456
01.06.92	78	88.7	78.3	8.7	14.8	19.1	66.1	232	304
15.09.92	26	267	615	121	6.96	11.3	106	1000	1610
15.09.93	37	505	1550	255	6.96	12.2	156	1960	3340
15.09.94	35	273	263	44.4	39.2	51.3	197	747	992
15.09.95	13	254	318	87.9	22.6	32.2	158	786	1100
15.09.96	22	157	138	29.6	25.2	33.1	117	410	535
15.09.97	21	274	171	37.4	74.0	90.5	232	598	731
18.09.98	32	504	461	81.8	78.3	103	371	1350	1770

* Obtained from the normalised distribution (Table 70) using an average deposition of 0.87 Bq m^{-2} for the Controlled Area.

Table 103. Distribution of ^{137}Cs in the whole body of adult men living in the Non-controlled (Observed) Area.*

Date of measurement	Number of people	Mean (Bq kg^{-1})	Standard deviation	Standard error	Percentiles				
					2.5%	5.0%	50%	95%	97.5%
01.09.86	762	740	656	23.6	120	157	552	1940	2540
15.03.87	119	389	200	18.4	132	156	346	768	908
15.09.87	13	563	338	93.6	159	193	484	1200	1460
15.09.97	15	177	186	48	21.6	29.6	122	508	684
18.09.98	20	460	600	134	38.4	54.4	281	1450	2060

* Obtained from the normalised distribution (Table 71) using an average deposition of 0.40 Bq m^{-2} for the Non-controlled Area.

Table 104. Distribution of ^{137}Cs in the whole body of adult women living in the Controlled Area.*

Date of measurement	Number of people	Mean (Bq kg^{-1})	Standard deviation	Standard error	Percentiles				
					2.5%	5.0%	50%	95%	97.5%
01.09.86	1631	1640	2270	56.6	123	177	966	5310	7610
15.03.87	71	387	278	33.1	86.1	109	315	914	1150
15.09.87	46	260	229	33.9	42.6	55.7	196	681	887
15.10.90	53	175	334	46.1	6.96	10.4	80.9	626	966
15.03.91	17	104	109	26.1	13.1	17.4	71.3	297	400
15.09.91	143	96.6	93.1	7.83	13.9	18.3	69.6	264	351
15.03.92	62	83.5	71.3	8.7	13.9	18.3	63.5	215	279
01.06.92	140	62.6	49.6	4.35	12.2	15.7	49.6	156	198
15.09.93	21	301	580	127	11.3	17.4	138	1080	1670
15.09.94	17	173	191	46.1	19.1	27.0	116	506	693
15.09.95	13	137	156	43.5	14.8	20.0	91.4	408	560
15.09.97	19	117	110	25.2	17.4	22.6	85.3	318	420
18.09.98	18	305	539	127	13.9	20.9	150	1070	1630

* Obtained from the normalised distribution (Table 72) using an average deposition of 0.87 Bq m^{-2} for the Controlled Area.

Table 105. Distribution of ^{137}Cs in the whole body of adult women living in the Non-controlled (Observed) Area.*

Date of measurement	Number of people	Mean (Bq kg^{-1})	Standard deviation	Standard error	Percentiles				
					2.5%	5.0%	50%	95%	97.5%
01.09.86	870	680	624	21.2	104	136	500	1820	2400
15.03.87	159	276	176	14	72.8	89.6	234	608	748
15.09.87	57	524	317	42	147	178	448	1130	1370
15.10.90	46	133	138	20.4	16.8	22.4	92.4	379	512
15.09.97	41	83.6	94.4	14.8	9.2	12.4	55.2	247	339
18.09.98	61	340	460	58.8	26.4	37.6	202	1090	1560

* Obtained from the normalised distribution (Table 73) using an average deposition of 0.40 Bq m^{-2} for the Non-controlled Area.

Table 106. Distribution of ^{137}Cs in the whole body of adult men and women (in total) living in the Controlled area.*

Date of measurement	Number of people	mean (Bq kg^{-1})	Standard deviation	Standard error	Percentiles				
					2.5 %	5.0 %	50 %	95 %	97.5 %
01.06.89	94	130	147	14.8	13.9	19.1	85.3	384	528
01.06.92	15	79.2	81.8	20.9	9.57	13.1	54.8	225	304
01.06.93	140	181	209	17.4	18.3	26.1	118	540	746
01.06.94	29	139	101	19.1	30.5	38.3	112	329	413

* Obtained from the normalised distribution (Table 74) using an average deposition of 0.87 Bq m^{-2} for the Controlled Area.

Table 107. Authors' estimates of the mean effective external dose from the Chernobyl ^{137}Cs in the test area.

Time period	Mean (mSv)	95% confidence interval Lower bound	Upper bound
Cloud Exposure	2×10^{-4}	0.7×10^{-4}	3.4×10^{-4}
Ground Expsoure			
28 April 1986 - 30 April 1987	3.53	2.84	4.22
28 April 1986 - 31 December 1990	11.1 (10.9)[a]	8.9 (8.8)	13.3 (13.0)
28 April 1986 - 31 December 1996	18.4 (17.6)	14.8 (14.1)	22.0 (21.1)
28 April 1986 - lifetime	39.6 (37.3)	31.8 (30.0)	47.4 (44.6)

[a] The values in parentheses indicate the estimated dose accounting for the effect of decontamination.

Table 108. Distribution of the individual external doses for a reference sample of the population in the investigated region according to the TL-measurements (normalized to a deposition of 1 MBq m^{-2}).

Duration months	Geom. mean mSv	Geom. std. dev.	Arith. mean ± std. error mSv	Std. dev. mSv	Percentiles, mSv 2.5%	5%	95%	97.5%
December 1986-December 1987								
12	2.23	1.36	2.34 ± 0.17	0.73	1.21	1.34	3.70	4.12
May 1989								
1	0.200	1.34	0.208 ± 0.012	0.063	0.111	0.123	0.324	0.359
October 1991								
1	0.132	1.44	0.141 ± 0.013	0.053	0.064	0.072	0.241	0.274
November 1992								
1	0.094	1.43	0.100 ± 0.006	0.037	0.046	0.052	0.170	0.192

Table 109. Distribution of individual external doses for a reference sample of the population in the investigated region according to the TL-measurements.

Duration months	Geom. mean mSv	Geom. std. dev.	Arith. mean ± std. error mSv	Std. dev. mSv	Percentiles, mSv 2.5%	5%	95%	97.5%
December 1986-December 1987								
12	1.59	1.71	1.84 ± 0.19	1.02	0.54	0.66	3.85	4.65
May 1989								
1	0.142	1.69	0.163 ± 0.015	0.084	0.050	0.060	0.338	0.406
October 1991								
1	0.094	1.77	0.111 ± 0.013	0.069	0.030	0.037	0.241	0.294
November 1992								
1	0.067	1.76	0.079 ± 0.007	0.048	0.022	0.026	0.170	0.208

Table 110. Authors' estimates of the average inhalation dose from Chernobyl ^{137}Cs.

Time period	Mean	95% confidence interval	
	mSv	Lower bound	Upper bound
Inhalation from cloud	0.013	0	0.03
Inhalation from resuspension			
28 April 1986 - 30 April 1987	0.026	0.022	0.029
28 April 1986 - 31 December 1990	0.027	0.023	0.031
28 April 1986 - 31 December 1995	0.027	0.023	0.031
28 April 1986 - lifetime	0.029	0.025	0.033

Table 111. Authors' estimates of the average ingestion dose from Chernobyl (Controlled Area, women), with the three major contributors to the dose.

Time period	Mean	95% confidence interval	
	mSv	Lower bound	Upper bound
28 April 1986 - 30 April 1987			
milk	3.23	2.22	4.24
meat	0.59	0.35	0.83
mushrooms	0.32	0.08	0.55
Total	4.44	3.37	5.51
28 April 1986 - 31 December 1990			
milk	3.23	2.22	4.24
mushrooms	1.32	0.07	2.56
meat	1.32	0.83	1.81
Total	6.29	4.57	8.02
28 April 1986 - 31 December 1995			
milk	4.04	2.74	5.35
mushrooms	2.47	0.13	4.81
meat	1.75	0.85	2.64
Total	8.89	6.01	11.77
28 April 1986 - lifetime			
milk	8.76	6.89	10.63
mushrooms	6.85	0	18.44
meat	2.81	0.15	5.47
Total	20.32	14.58	26.06

Table 112. Authors' estimates of the average ingestion dose from Chernobyl (Non-controlled Area, women), with the three major contributors to the dose.

Time period	Mean mSv	95% confidence interval Lower bound	Upper bound
28 April 1986 - 30 April 1987			
milk	3.55	2.42	4.69
meat	0.91	0.55	1.26
mushrooms	0.88	0.31	1.46
Total	5.67	4.34	7.00
28 April 1986 - 31 December 1990			
milk	6.93	4.82	9.03
mushrooms	3.66	0.5	6.82
meat	2.68	1.81	3.55
Total	13.84	9.92	17.77
28 April 1986 - 31 December 1995			
milk	8.86	6.3	11.41
mushrooms	6.87	0.9	12.83
meat	3.24	2.18	4.29
Total	19.64	13.03	26.24
28 April 1986 - lifetime			
mushrooms	19.04	0	95.97
milk	17.31	12.19	22.44
meat	3.45	2.8	4.1
Total	41.72	28.83	54.61

Table 113. Authors' estimates of the average ingestion dose from Chernobyl (Controlled Area, men), with the three major contributors to the dose.

Time period	Mean mSv	95% confidence interval Lower bound	Upper bound
28 April 1986 - 30 April 1987			
milk	3.89	2.63	5.15
mushrooms	0.64	0.18	1.09
meat	0.49	0.28	0.69
Total	5.31	3.95	6.67
28 April 1986 - 31 December 1990			
milk	3.89	2.63	5.15
mushrooms	2.63	0.21	5.06
meat	0.98	0.59	1.36
Total	7.88	5.09	10.68
28 April 1986 - 31 December 1995			
mushrooms	4.94	0.38	9.51
milk	4.61	2.96	6.25
meat	1.53	0.95	2.12
Total	11.57	6.64	16.5
28 April 1986 - lifetime			
mushrooms	13.71	0	58.09
milk	8.51	5.72	11.3
meat	1.87	1.47	2.27
Total	26.48	16.68	36.28

Table 114. Authors' estimates of the average ingestion dose from Chernobyl (Non-controlled Area, men), with the three major contributors to the dose.

Time period	Mean	95% confidence interval	
	mSv	Lower bound	Upper bound
28 April 1986 - 30 April 1987			
milk	4.75	3.26	6.23
mushrooms	1.2	0.4	2.01
meat	1.26	0.79	1.73
Total	7.56	5.8	9.33
28 April 1986 - 31 December 1990			
milk	9.67	6.42	12.91
mushrooms	4.98	0.58	9.37
meat	3.3	1.96	4.64
Total	18.73	13.09	24.37
28 April 1986 - 31 December 1995			
milk	11.69	7.69	15.68
mushrooms	9.34	1.06	17.62
meat	4.03	2.41	5.66
Total	25.99	16.63	35.35
28 April 1986 - lifetime			
mushrooms	25.89	0	173.22
milk	20.96	8.04	33.87
meat	4.46	2.78	6.14
Total	54.09	36.07	72.12

Table 115. Authors' estimates of the average total effective dose from Chernobyl ^{137}Cs (Controlled area, women), with the three major contributors.

Time period	Mean (mSv)	95% confidence interval	
		Lower bound	Upper bound
28 April 1986 - 30 April 1987			
Total:	8.3	7.0	9.7
Internal (ingestion): 53%	4.4	3.4	5.5
External (from ground): 47%	3.9 (0.39)	3.2	4.7
Internal (inhalation from resuspension)	0.026	0.022	0.029
28 April 1986 - 31 December 1990			
Total:	18.6	15.6	21.6
External (from ground): 66%	12.3 (1.22)	9.9	14.7
Internal (ingestion): 34%	6.3	4.6	8.0
Internal (inhalation from resuspension)	0.027	0.023	0.031
28 April 1986 - 31 December 1995			
Total:	29.3	24.7	34.2
External (from ground): 70%	20.4 (2.04)	16.4	24.4
Internal (ingestion): 30%	8.9	6.0	11.8
Internal (inhalation from resuspension)	0.027	0.023	0.031
28 April 1986 - lifetime			
Total:	64.3	53.9	74.7
External (from ground): 68%	44.0 (4.39)	35.4	52.6
Internal (ingestion): 32%	20.3	14.6	26.1
Internal (inhalation from resuspension)	0.029	0.025	0.033

Table 116. Authors' estimates of the average total effective dose from Chernobyl ^{137}Cs (Non-controlled area, women), with the three major contributors.

Time period	Mean (mSv)	95% confidence interval Lower bound	Upper bound
28 April 1986 - 30 April 1987			
Total:	7.5	6.1	8.9
Internal (ingestion): 76%	5.7	4.3	7.0
External (from ground): 24%	1.8 (0.18)	1.5	2.2
Internal (inhalation from resuspension)	0.026	0.022	0.029
28 April 1986 - 31 December 1990			
Total:	19.5	15.5	23.6
Internal (ingestion): 71%	13.8	9.9	17.8
External (from ground): 29%	5.7 (0.56)	4.6	6.8
Internal (inhalation from resuspension)	0.027	0.023	0.031
28 April 1986 - 31 December 1995			
Total:	29.0	22.1	35.9
Internal (ingestion): 68%	19.6	13.0	26.2
External (from ground): 32%	9.4 (0.92)	7.6	11.2
Internal (inhalation from resuspension)	0.027	0.023	0.031
28 April 1986 - lifetime			
Total:	61.9	48.4	75.4
Internal (ingestion): 67%	41.7	28.8	54.6
External (from ground): 33%	20.2 (2)	16.2	24.2
Internal (inhalation from resuspension)	0.029	0.025	0.033

Table 117. Authors' estimates of the average total effective dose from Chernobyl ^{137}Cs (Controlled area, men), with the three major contributors.

Time period	Mean (mSv)	95% confidence interval	
		Lower bound	Upper bound
28 April 1986 - 30 April 1987			
Total:	9.2	7.6	10.8
Internal (ingestion): 58%	5.3	4.0	6.7
External (from ground): 42%	3.9	3.2	4.7
Internal (inhalation from resuspension)	0.026	0.022	0.029
28 April 1986 - 31 December 1990			
Total:	20.2	16.5	23.9
External (from ground): 61%	12.3	9.9	14.7
Internal (ingestion): 39%	7.9	5.1	10.7
Internal (inhalation from resuspension)	0.027	0.023	0.031
28 April 1986 - 31 December 1995			
Total:	32.0	25.9	38.3
External (from ground): 64%	20.4	16.4	24.4
Internal (ingestion): 36%	11.6	6.6	16.5
Internal (inhalation from resuspension)	0.027	0.023	0.031
28 April 1986 - lifetime			
Total:	70.5	57.5	83.5
External (from ground): 62%	44.0	35.4	52.6
Internal (ingestion): 38%	26.5	16.7	36.3
Internal (inhalation from resuspension)	0.029	0.025	0.033

Table 118. Authors' estimates of the average total effective dose from Chernobyl ^{137}Cs (Non-controlled area, men), with the three major contributors.

Time period	Mean (mSv)	95% confidence interval	
		Lower bound	Upper bound
28 April 1986 - 30 April 1987			
Total:	9.4	7.6	11.2
Internal (ingestion): 81%	7.6	5.8	9.3
External (from ground): 19%	1.8	1.5	2.2
Internal (inhalation from resuspension)	0.026	0.022	0.029
28 April 1986 - 31 December 1990			
Total:	24.4	18.7	30.2
Internal (ingestion): 77%	18.7	13.1	24.4
External (from ground): 23%	5.7	4.6	6.8
Internal (inhalation from resuspension)	0.027	0.023	0.031
28 April 1986 - 31 December 1995			
Total:	35.4	25.9	44.9
Internal (ingestion): 73%	26.0	16.6	35.4
External (from ground): 27%	9.4	7.6	11.2
Internal (inhalation from resuspension)	0.027	0.023	0.031
28 April 1986 - lifetime			
Total:	74.3	55.8	92.8
Internal (ingestion): 73%	54.1	36.1	72.1
External (from ground): 27%	20.2	16.2	24.2
Internal (inhalation from resuspension)	0.029	0.025	0.033

ACKNOWLEDGEMENTS

The Iput River scenario was developed on the basis of observations made in the Bryansk Region of Russia by scientists from three Russian research institutes: (1) the Institute of Experimental Meteorology, SPA "Typhoon," Obninsk, Russia, data on radioactive contamination of the environment and geophysical data; (2) the Institute of Agricultural Radiology and Ecology, Obninsk, Russia, information about radioactive contamination of agricultural produce and characteristics of agricultural ecosystems; and (3) the Institute of Radiation Hygiene, St. Petersburg, Russia, measurements of the ^{137}Cs content in humans and dosimetric information. The model-testing scenario was prepared by the following individuals: I. I. Kryshev, T. G. Sazykina, I. V. Dragolybova, and A. I. Nikitin (Institute of Experimental Meteorology); S. V. Fesenko, N. I., Sanzharova, S. I. Spiridonov, A. I. Panov, I. A. Gontarenko, and R. M. Alexakhin (Institute of Agricultural Radiology and Ecology); M. I. Balonov, G. J. Bruk, V. Yu. Golikov, I. G. Travnikova, T. Jesko, and A. Bazukin (Institute of Radiation Hygiene); and F. O. Hoffman and K. M. Thiessen (SENES Oak Ridge, Inc., Center for Risk Analysis, Oak Ridge, Tennessee, U.S.A.).

REFERENCES AND RELEVANT PUBLICATIONS

Alexakhin, R.M. 1993. Countermeasures in Agricultural Production as an Effective Means of Mitigating the Radioecological Consequences of the Chernobyl Accident. *The Science of the Total Environment* 137:9-20.

Balonov, M.I., Travnikova, I.G. 1993. Importance of diet and protective actions on internal dose from Cs radionuclides in inhabitants of the Chernobyl region. In: The Chernobyl Papers, Vol. I., Ed. by S.E. Merwin and M.I. Balonov, Richland, Research Enterprises, pp. 127-166.

Balonov, M.I., Bruk, G., Golikov, V., Erkin, V.G., Zvonova, I.A., Parkhomenko, V.I., Shutov, V.N. 1995. Long term exposure of the population of the Russian Federation as a consequence of the accident at the Chernobyl power plant. In: Environmental Impact of Radioactive Releases. IAEA, Vienna, pp. 397-411.

Balonov, M.I., Golikov, V.Y., Erkin, V.G., Parchomenko, V.I., Ponomarev, A. 1992. Theory and practice of a large-scale programme for the decontamination of the settlements affected by the Chernobyl accident. In: Proc. Int. Seminar on Intervention Levels and Countermeasures for Nuclear Accidents. Cadarache, 7-11 Oct. 1991, Report EUR 14469, pp. 397-415.

BIOMASS (The IAEA Programme on Biosphere Modelling and Assessment Methods). 2000. Model Testing Using Chernobyl Fallout Data from the Iput River Catchment Area, Bryansk Region, Russia: Scenario “Iput.” BIOMASS Theme 2, Environmental Releases, Dose Reconstruction Working Group. International Atomic Energy Agency, Vienna, BIOMASS/T2DR/WD02.

Brown, J., et al. 1995. Comparison of Data from the Ukraine, Russia and Belarus on the effectiveness of agricultural countermeasures. Memorandum NRPB-M597; 1-27.

Bruk, G., Shutov, V., Travnikova, I., Balonov, M., Kaduka, M., Basalaeva, L. 1999. The role of the forest products in the formation of internal doses to the population of Russia after the Chernobyl accident. In: Contaminated Forests. Ed. by I. Linkov and W.R. Shell. Kluwer Academic Publishers, pp. 343-352.

Bruk, G.Ya, Shutov, V.N., Balonov, M.I., Basalayeva, I.N., Kislov, M.V. 1998. Dynamics of ^{137}Cs content in agricultural food products in regions of Russia contaminated after the Chernobyl accident. *Radiation Protection Dosimetry* 76:160-178.

Fesenko, S.V., Alexakhin, R.M., Spiridonov, S.I., Sanzharova, N.I. 1995. Dynamics of ^{137}Cs concentration in agricultural production in areas of Russia subjected to contamination after the accident at the Chernobyl Nuclear Power Plant. *Radiation Protection Dosimetry* 60(2):155-166.

Fesenko, S.V., Colgan, P.A., Sanzharova, N.I., Lissianski, K.B., Vazquez, C., Guardans, R. 1997. The dynamics of the transfer of caesium-137 to animal fodder in areas of Russia affected by the Chernobyl accident and resulting doses from the consumption of milk and milk products. *Radiation Protection Dosimetry* 69(4):289-299.

Frank, G., Jacob, P., Pröhl, G., Smith-Briggs, J.L., Sandalls, F.J., Holden, P.L., et al. 1997. *Optimal Management Routes for the Restoration of Territories Contaminated during and after the Chernobyl Accident*. Final Report for the contracts COSU-CT94-0101, COSU-CT94-0102 and B7-6340/95/001064/MAR/C3 of the European Commission.

Golikov, V., Balonov, M., Erkin, V., Jacob, P. 1999. Model validation for external doses due to environmental contaminations by the Chernobyl accident. *Health Physics* 77(6):654-661.

IAEA (International Atomic Energy Agency). 1995. Validation of models using Chernobyl fallout data from the Central Bohemia region of the Czech Republic--Scenario CB. First Report of the VAMP Multiple Pathways Assessment Working Group. International Atomic Energy Agency, Vienna, IAEA-TECDOC-795.

IAEA (International Atomic Energy Agency). 1996. Validation of models using Chernobyl fallout data from southern Finland--Scenario S. Second Report of the VAMP Multiple Pathways Assessment Working Group. International Atomic Energy Agency, Vienna, IAEA-TECDOC-904.

IAEA (International Atomic Energy Agency). 1997. The use of Prussian Blue to reduce radiocaesium contamination of milk and meat produced on territories affected by the Chernobyl accident. Report of United Nations Project E11, IAEA-TECDOC-926, Vienna, ISSN 1011-4289.

Jacob, P., Likhtarev, I. (Eds.) 1996. *Pathway analysis and dose distributions (JSP 5)*. European Commission Directorate General XII: Brussels, EUR 16541 EN.

Jacob, P., Pröhl, G., Likhtarev, I., Kovgan, L., Gluvchinsky, R., Perevoznikov, O., Balonov, M.I., Golikov, V., Ponomarev, A., Erkin, V., Vlasov, A., Shutov, V.N., Bruk, G.I., Travnikova, I.G., Kenigsberg,Y.E., Buglova, E.E., Shevchuk, V.E., Morrey, M., Prosser, S.L., Jones, K.A., Colgan, P.A., Guardans, R., Suacez, A., Renaud, Ph., Maubert, H., Skryabin, A.M., Vlasova, N., Linge, I., Epifanov, V., Osipyants, I., Skorobogotov, A. 1996. Pathway analysis and dose distributions. European Commission, Brussels: EUR 16541 EN: 1-130.

Jacob, P., Rosenbaum, H., Petoussi, N., Zankl, M. 1990. Calculation of organ doses from environmental gamma rays using human phantoms and Monte Carlo methods. Part II: Radionuclides distributed in the air or deposited on the ground. GSF-National Research Center on Environment and Health. Neuherberg, Germany: GSF-Bericht 12/90.

Kryshev, I.I. 1996. Radioactive contamination of aquatic ecosystems in the areas of nuclear power plants and other nuclear facilities in Russia. *Radiochimica Acta* 74:199-202.

Lebedev, O.V., Yakovlev, V.A. 1993. The correlation between ^{137}Cs half-time and age, body mass and height in individuals contaminated from the Chernobyl accident. In: Merwin, S.E., and Balonov, M.I., editors. The Chernobyl Papers. Vol. 1. Doses to the Soviet Population and Early Health Effects Studies. Richland, Washington, USA, Research Enterprises, pp. 221-46.

Linsley, G.S. 1978. Resuspension of the transuranium elements - A review of existing data. NRPB-75, HMSD, London.

Makhonko, K.P. (Ed.). 1990. A Manual on the Establishment of Control over the State of the Natural Environment in the Area of Nuclear Power Plants Location. Gidrometeoizdat, Leningrad (in Russian).

Meckbach, R., Jacob, P. 1998. Gamma exposures due to radionuclides deposited in urban environments. Part II: Location factors for different deposition patterns. *Radiation Protection Dosimetry* 25:181-190.

Ratnikov, A.N., Vasiliev, A.V., Krasnova, E.G., Pasternak, A.D., Howard, B.J., Hove, K., Strand, P. 1998. The use of hexacyanoferrates in different forms to reduce radiocaesium contamination of animal products in Russia. *The Science of the Total Environment* 223:167-176.

Reconstruction of the mean effective dose accumulated in 1986-1995 by inhabitants of localities of the Russian Federation subjected to radioactive contamination due to the Chernobyl accident in 1986. 1996. Methodic Instruction of the Russian Ministry of Public Health, Nr. MU - 2.6.1.579-96.

Sanzharova, N.I., Fesenko, S.V., Kotik, V.A., Spiridonov, S.I. 1996. Behaviour of radionuclides in meadows and efficiency of countermeasures. *Radiation Protection Dosimetry* 64(1/2):43-48.

Shutov, V.N., Bruk, G.Ya., Balonov, M.I., Parhomenko, V.I., Pavlov I.Ju. 1993. Cesium and strontium radionuclide migration in the agricultural ecosystem and estimation of doses to the population. In: The Chernobyl Papers, Vol.1., Ed. by S.E. Merwin and M.I. Balonov, Richland, Research Enterprises, pp. 167-218.

Shutov, V.N., Bruk, G.Ya, Basalaeva, L.N., Vasilevetskiy, V.A., Ivanova, N.P., Karlin, I.S. 1996. The role of mushrooms and berries in the formation of internal exposure doses to the population of Russia after the Chernobyl accident. *Radiation Protection Dosimetry* 67(1):55-64.

Strand, P., Balonov, M., Travnikova, I., Hove, K., Skuterud, L., Prister, B., Howard, B.J. 1999. Fluxes of radiocaesium in selected rural study sites in Russia and Ukraine. *The Science of the Total Environment* 231:159-171.

Strand, P., Howard, B., Averin V., (Eds.). 1996. *Transfer of radionuclides to animals, their comparative importance under different agricultural ecosystems and appropriate countermeasures (ECP 9)*. European Commission Directorate General XII: Brussels, EUR 16539 EN.