DRAFT

Scenario description for development of the radiological situation in three different towns of Ukraine, contaminated as a result of the Chornobyl Nuclear Accident

Kiev – Vienna

October 2004

EMRAS Urban Remediation Working Group

Abstract
This document provides a model-testing scenario based on Chornobyl (Chernobyl) fallout data for three Ukrainian towns which have different characteristics and present a variety of exposure concerns. Pripyat was evacuated soon after the Chornobyl accident and has remained essentially uninhabited. Polesskoe remained inhabited after the accident. Slavutych was built after the accident on contaminated land. Different sets of remediation activities were carried out in the three locations. This combination of towns will provide an opportunity for modellers to compare differences in redistribution processes, exposure situations, and remedial activities for the same initial contamination event. The model-testing scenario will be addressed first without consideration of remediation efforts and then with the remediation efforts included. Test data (measurements) are available for a number of modeling endpoints; additional endpoints will also be used for model intercomparison.

Acknowledgements
Preparation of this modelling scenario has been carried out by Andrey Arkhipov of the Chernobyl Centre of Radioecology “ECOCENTRE”, Sergij Gaschak of the Chernobyl Center for Nuclear Safety, Radioactive Waste & Radioecology, and Borys Zlobenko of the State Scientific Center of Environmental Radiogeochemistry.

Table of Contents

I. Introduction

All of the towns—Pripyat, Slavutych and Polesskoe—are situated in the northern districts of Ukraine, within a 60-km radius of the Chornobyl Nuclear Power Plant (Chornobyl NPP). Pripyat is the biggest settlement by population (more than 49,000), and closest to the NPP. As a result of the accident on April 26, 1986, it received the most contamination. All of the population of the town was evacuated by the evening of April 27, 1986, and it has remained uninhabited since 1986. Slavutych and Polesskoe are almost half the size of Pripyat by population. They are located northeast and southwest of the Chornobyl NPP, respectively. Slavutych was built on contaminated lands after the accident. Polleskoe was contaminated by the Chornobyl fallout; however, it remained populated through all of the post-accidental period. Decontamination activities were carried out in all of these towns. The principal difference between Pripyat and the other contaminated towns is the quick evacuation of the population from Pripyat, after which decontamination work was conducted. The other difference is the extremely high level of contamination of Pripyat which leaves no hope for future settling of the town.

Brief description of the accident at the Chornobyl[1] NPP

In the context of urban radioecological study, the main interest is what radioactive fallout resulted, and when and where it fell out over all of the days of the active phase of the Chornobyl accident. According to a number of assessments, the series of heat explosions in the fourth Chornobyl power unit were caused by actions of the operating staff and due to the nuclear-physical conditions that arose and to the constructional peculiarities of the nuclear reactor [Chornobyl catastrophe, 1997]. The safety system of the reactor and its building were destroyed. Products of nuclear fuel processing and of the reactor constructional materials were released to the environment. The largest releases continued for 10 days until May 6, 1986, and their distribution depended on fractional composition, height of elevation in the atmosphere, and meteorological conditions near the reactor and in regions where the radioactive clouds passed [Chernobyl, 1990; Chornobyl catastrophe, 1997].

The first radioactive cloud, which had formed during the explosion, under conditions of steady night weather, was elevated to 300-500 m height and went to the west, creating a long (up to 100 km) and almost straight, narrow trace [Chernobyl, 1990]. It passed south of Pripyat's residential buildings by 1.5-2 km. This trace fallout contained many unoxidized fuel particles, some of which were very large (up to 10^1-10^2 µm) and was deposited on the first kilometers of the cloud's path [Kashparov, 2001]. Also, in a moment of the explosion, almost all of the reactor's noble gases were released into the atmosphere [Chernobyl, 1990]. Further, during natural fuel heat-up and graphite stack burning (up to 1800-2000 °K), a spurt of radioactive releases was elevated to 1000-1200 m height and directed to the northwest [Chernobyl, 1990; Chornobyl catastrophe, 1997], bending round Pripyat. They were enriched by highly mobile, volatile radionuclides (I, Te, Cs) and finely dispersed, oxidized fuel particles (1-3 µm). In the surface layer of the atmosphere, the air current was transferred mainly to the west and southwest directions. By noon of April 26, the plume reached the settlement of Polesskoe and crossed it by a narrow trace. The dose rate reached 0.1-0.6 mR/h there (in some places, 2.0 mR/h) [Nad'yarnyh, 1989].

On April 27, the north and northwest directions of surface air currents prevailed. This caused a quick worsening of the radiation situation in Pripyat. On April 26, the radiation level in the

[1] "Chernobyl" is a transliteration from Russian.

town was 0.014-0.13 R/h, but by the evening of April 27, this level had reached 0.4-1.0 R/h, and in some places, 1.5 R/h [Chornobyl catastrophe, 1997] (by other data, up to 4-7 R/h [Repin, 1995]). During the period of 14:00-16:30, all of the town's residents were evacuated. The strongest radioactive fallout occurred along the eastern outskirts of the town. Although in that time the releases were enriched by small particle aerosols with sublimated radionuclides, they had some heavy products of burning which precipitated on the closest territories, including Pripyat's surroundings.

On April 28-29, the radioactive releases began to lose height (600 m) and activity, and the transfer turned gradually to the northeast [Chernobyl, 1990]. Evidently, radioactive fallout in the northwest part of the Chernigov region (left-bank lands of the Dnieper river) occurred from the night of April 27/28 until April 29. Unlike the fallout that took place in Pripyat and Polesskoe previously, radioactive precipitation was partially wet there, which caused the formation of several radioactive spots. In 1986 there were only a few small villages, but some time later (1987-1989), the new town of Slavutych was built just on the radioactive spots.

Because of a considerable decrease of reactor core temperature, the intensity of the radioactive releases gradually dropped by April 30 (up to 6 times [Chernobyl, 1990]). This promoted the intensive oxidizing of fuel [Kashparov, 2001] and determined the character of further releases. As a result of the first countermeasures undertaken, the reactor core was very filled up, which made heat exchange worse and became a reason for a new active stage of the accident. Starting May 2-3, 1986, the reactor core warmed up again. Radioactive releases had a large fraction of dispersed oxidized fuel particles. Because the prevailing direction of air currents had changed since the afternoon of April 29, the main plumes of the Chornobyl fallout lay to the south [Chernobyl, 1990]. That continued till May 6, 1986, when the intensity of the releases dropped to 1% of the initial one and less. Further radioactive releases continued to decrease, and almost ended by May 25, 1986 [Chernobyl, 1990]. The following picture (Figure I-1) shows the trajectory of radioactive traces during different periods of the accident [Chernobyl, 1990].

Thus, the Chornobyl accident and the following spread of radioactive releases caused contamination of broad territories in Europe, including several urban areas. The towns—Pripyat, Chornobyl, Polesskoe and Slavutych—received deposition containing a wide spectrum of nuclear fission products, isotopes of induced activity, and transuranium elements. Fallout in the town of Pripyat was mainly in the form of finely dispersed fuel, and the total level of deposition reached up to 80-24000 kBq/m^2 of ^{137}Cs, 50-6660 kBq/m^2 of ^{90}Sr, and 1.5-200 kBq/m^2 of $^{239+240}$Pu [Baryakhtar, 2003]. Radioactive fallout in the town of Polesskoe was remarkably less—up to 300-3700 kBq/m^2 of ^{137}Cs, 30-280 kBq/m^2 of ^{90}Sr, and 0.3-7.4 kBq/m^2 of $^{239+240}$Pu [Gavriluk et al., 1990; Gavriluk et al., 1992], and was represented by more small particles. Finally, the contamination of Slavutych did not exceed 480 kBq/m^2 of ^{137}Cs, 37 kBq/m^2 of ^{90}Sr, and 0.74 kBq/m^2 of $^{239+240}$Pu [Nosovsky et al., 2001], and partially was represented by wet fallout of the condensed fraction of the releases.

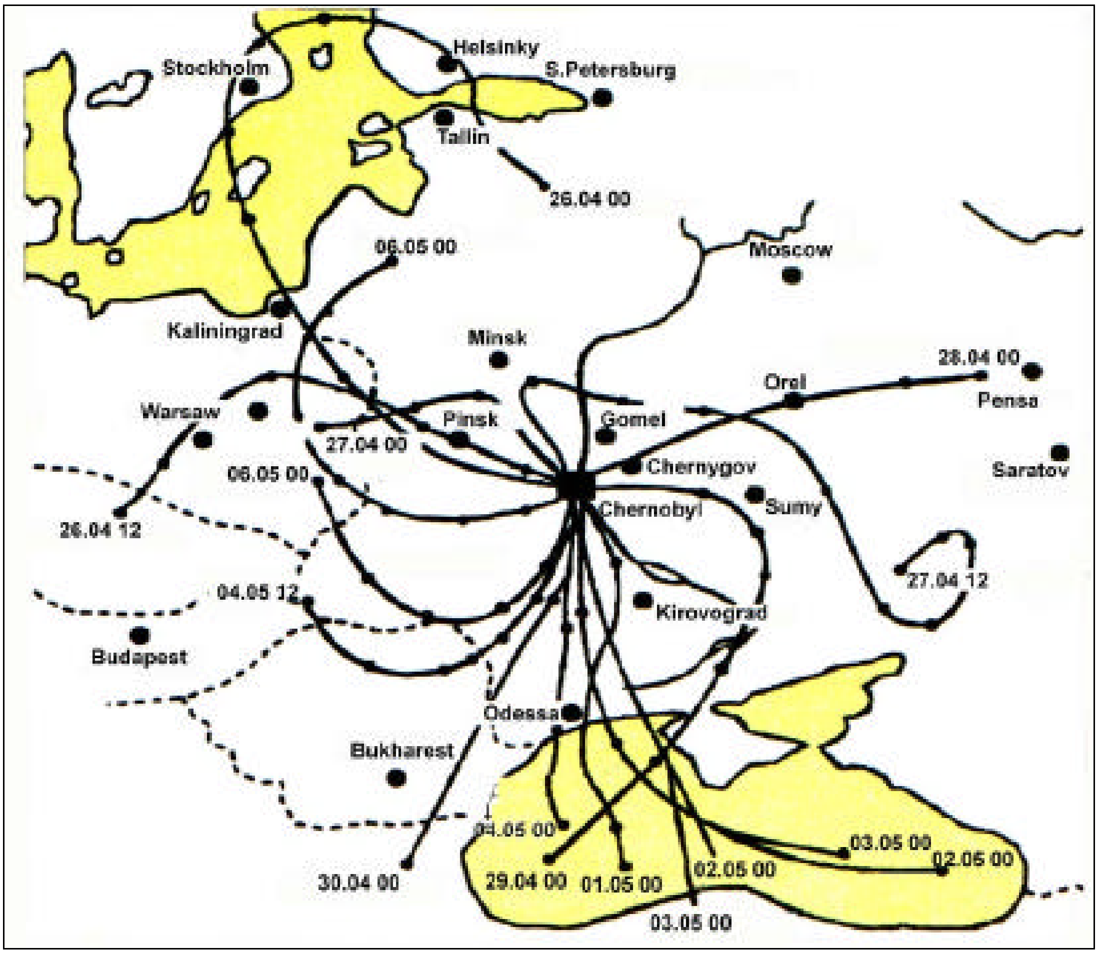


Figure I-1. Trajectories of radioactive traces during the accident, based on [Kasharov, 2001].

Overview of the model-testing exercise

The overall objective of the EMRAS Urban Remediation Working Group is to test and improve the prediction of dose rates and cumulative doses to humans for urban areas contaminated with dispersed radionuclides, including (a) prediction of changes in radionuclide concentrations or dose rates as a function of location and time, (b) identification of the most important pathways for human exposure, and (c) prediction of the reduction in radionuclide concentrations or dose rates expected to result from various countermeasures or remediation efforts. The present scenario provides an opportunity to compare and test approaches and models for assessing the significance of a given contamination situation and for guiding decisions about countermeasures or remediation measures implemented to reduce doses to humans or to clean up the contaminated area.

The scenario description (this document and accompanying documents and files) provides description of the situation to be modeled (input information) and a list of the endpoints to be modeled for each of the three towns. Participants in the model-testing exercise are asked to submit initial model predictions (with uncertainties) for these endpoints, together with documentation of their model and their selected parameter values or distributions. The Working Group will use these predictions for model-to-model comparison. Participants will then have an opportunity to revise their predictions and to submit any revised predictions (with documentation). The final predictions will be compared with test data (to the extent that test data are available). Participants will be asked to evaluate their model performance and identify major sources of uncertainty in their model predictions. The final report of the test exercise will include discussion of the model-model comparison, the comparison of model predictions with test data, performance of the various models, important sources of uncertainty in the predictions, and areas for which further research could be beneficial.

Modelling endpoints

Although all three towns selected for the modeling scenario were contaminated due to the same event, they differ in their initial contaminant distributions, the relevant redistribution processes, the exposure situations of concern, and the remedial activities that have been carried out. Pripyat was evacuated soon after the Chornobyl accident and has remained essentially uninhabited. Polesskoe remained inhabited after the accident. Slavutych was built after the accident on contaminated land. The modelling endpoints for each town are listed in Table I-1, along with the locations to be used for modelling and a summary of the types of input information. The model-testing scenario will be addressed first without consideration of remediation efforts and then with the remediation efforts included. All endpoints will be used for model intercomparison; where test data (measurements) are available, the model predictions will also be compared to those data.

Table I-1. Summary of modeling scenario for the Urban Remediation Working Group.

Town	Locations for modeling exercise	Input information	Modeling endpoints
Pripyat	District #4 (with decontamination, young vegetation, 800 people in 1989-1994, lots of 9-story buildings) District #1 (without decontamination, similar buildings, older vegetation, no inhabitants)	Measurements from May 1986 Information about decontamination efforts (in some areas; 1986-1988)	Dose rates and contaminant distributions, with and without remediation, for 1986 (June, July, August, September, 4th quarter) and annually for 1987-1999
Polesskoe	Volya Street First of May Street	1986 dose rates 1988 information for individual buildings 1989 radionuclide distributions in soil (soil profile) Information about remediation activities	Dose rates and contaminant distributions, with and without remediation, annually for 1990-1998
Slavutych	A district built in 1987 with mixed soil and decontamination after the buildings were built Other districts, with decontamination before the buildings were built (both have multi-story residential areas and 1-2 story buildings with kitchen gardens)	Initial contamination of area γ radionuclides in soil and air Information types of buildings, dates of construction Information about major decontamination efforts (1988-1990) Chronology or timeline Information on surrounding areas with no decontamination	Dose rates and contaminant distributions, by season or part of year for 1988-1990 (during decontamination) and annually for 1990-1999 (after decontamination)

II. Pripyat

History of town

The town of Pripyat was established in 1970 (on the place of a village called Semykhody and close to a village called Novoshepelychy) as a town for the staff and builders of the Chornobyl NPP and related facilities and services. The town of Pripyat occupies nearly 600 ha (including 42 ha of lawns and forest areas). In 5 microdistricts there are 149 multistoried buildings. The total apartment area is about 520,000 m^2 (13500 flats and up to 30000 rooms). The total length of underground communications is 135 km, including 52 km of heating main. The area of industrial premises is 30000 m^2, and of other non-residential buildings, 10000 m^2 [Nad'yarnyh et al., 1989].

All of the population (up to 49,360 at the moment of the accident) was evacuated in 1986 as a result of accidental radioactive contamination, and it is remained uninhabited since then. Different kinds of decontamination works were fulfilled there during 1986-1990, which allowed for the use of some buildings, communications and areas for temporary placement of research, monitoring, service and industrial enterprises which worked on problems of the Chornobyl zone and NPP until 1994-1998. Later the town became almost totally abandoned. It remains as an area of restricted access.

Location and landscape (town description)

The town of Pripyat is situated 3 km northwest of the Chornobyl NPP (2.7 km from the destroyed fourth unit to the closest residential buildings, 3.5 km to the town center), on the right bank of the river bearing the same name, on the first terrace above the floodplain (Figure II-1). The town surface topography is mainly flat, with a small slope towards the floodplain. Within most of the region, the elevation amounts to 112.5 m, with only the southeastern outskirts containing hilly uplands up to 118-120 m above sea level. The altitude differential at the terrace is approximately 5-7 m. From the northeast, the following floodplain water basins directly approach the town area: Pripyat backwater and Semykhody oxbow. Before the accident, these water basins flowed into the Pripyat River. The surroundings of the town iinclude meadows of the river floodplain and the first terrace (some of them were arable lands before the accident); spotted spread of pine tree plantations (mainly 15-30 years old) along the southeast, south and southwest outskirts; and 90 ha of sandy plateaus, up to 5-7 m high, inwashed by the floodplain northeast of Pripyat for future building (at the moment of the accident, the sands had no surface fixation). The town had railway, river and developed road communications with other regions.

Structure of the urban area

The town has an area of up to 4.5-5 km^2 (together with the Chornobyl NPP industrial area, forest areas and sand plateau, up to 18-20 km^2). Structurally, there are eight residential micro-districts (#1, 1a, 2, 3, 3a, 4, 4a, 5) within the town area (Figure II-2), as well as some adjacent sectors that were used as industrial and recreational zones or were being prepared for further buildup. Microdistricts #1, 1a, 2, and 3 (closest to the NPP) are the oldest (5-15 years by 1986); these areas had developed tree and bush vegetation. The wood vegetation of new microdistricts #4, 4a, and 5 (opposite side of the town from the NPP) was mainly developed after the accident. The buildings occupy approximately 18% of the total residential area (Figure II-3); asphalt and concrete coverings, 20%; natural conditions (pine forests), not more than 12%; gardens with cultivated soils, 4%; lawns, public gardens, and other town green areas, 24%; other areas, 23%. There is a public park (up to 10 ha) and sport stadium. The forest plantations occupy approximately 20% of the surrounding lands; the rest is mostly

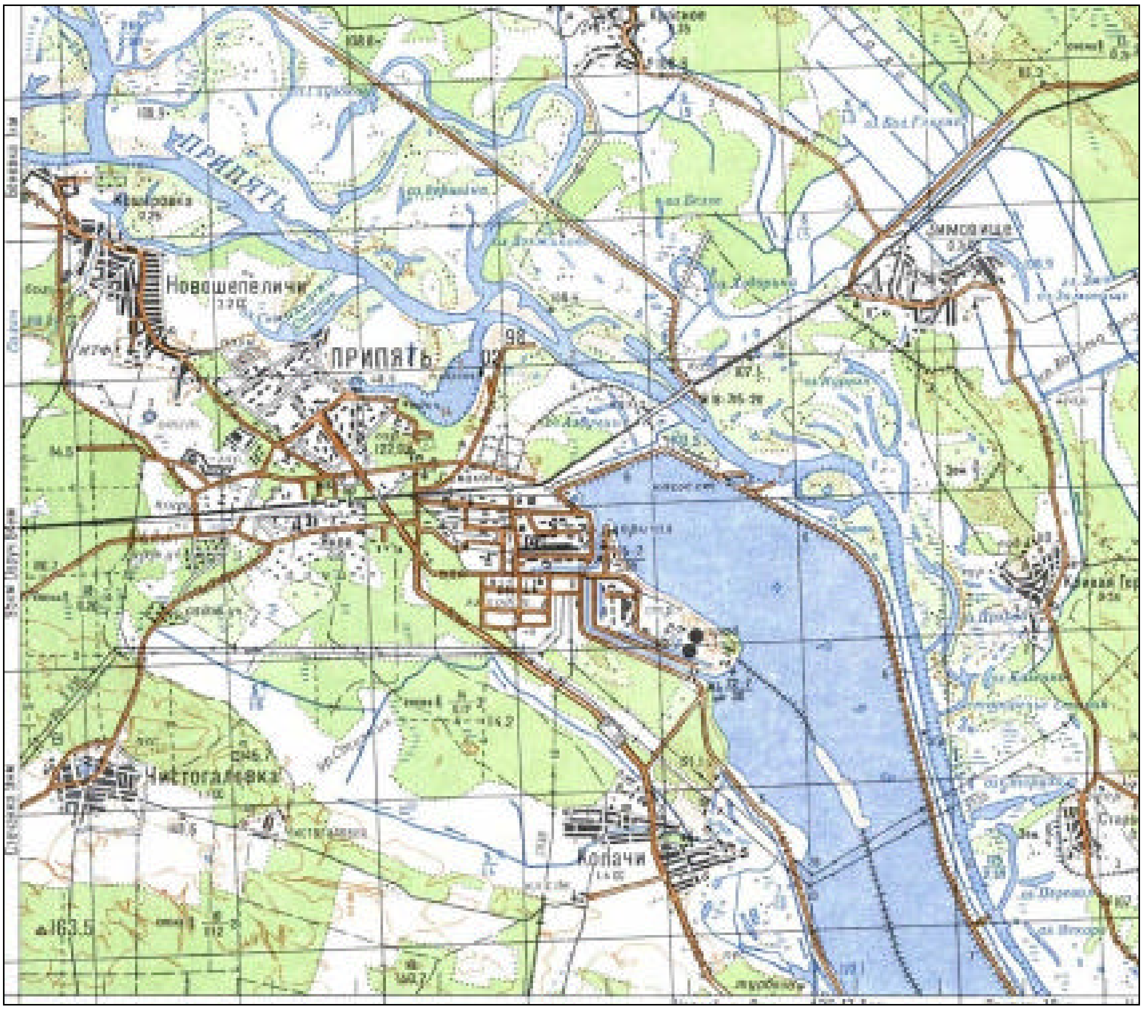


Figure II-1. – Part of raster map, showing the location of the town of Pripyat near the Chornobyl Nuclear Plant (1:100 000).

industrial areas (Figure II-4). The town has a developed system of industrial and storm sewage, road network, and other communications.

Type of soil and vegetation

There are three variants of soil and hydrological conditions within the town territory. The southeastern part is located in the artificially planned hilly terrace above the floodplain, which consists of well-selected sands more than 2 m thick and the soddy, weakly podzolic soils that have formed above them. Before construction activities started, there had grown white-mossed and green-mossed pine forests of artificial origin. The central main part of the town (up to 50% of its total area) is situated on these same sands, but with clay veins; soils are represented by soddy, weakly podzolic powder-sandy ones.

Before the town was constructed, these plots had been partially ploughed up (or used for pasture) and partially planted with pine-tree plantations, which further became a part of the town's woodland plantations. The northwestern part of the town is located in powder sands with light loam and loamy-sand interbeds at the depth of 0.3-0.7 m; soil covering is composed of soddy-podzolic powder-sandy soils, which become clayey below a depth of 0.3-0.4 m. These plots had been ploughed up before the town was constructed.

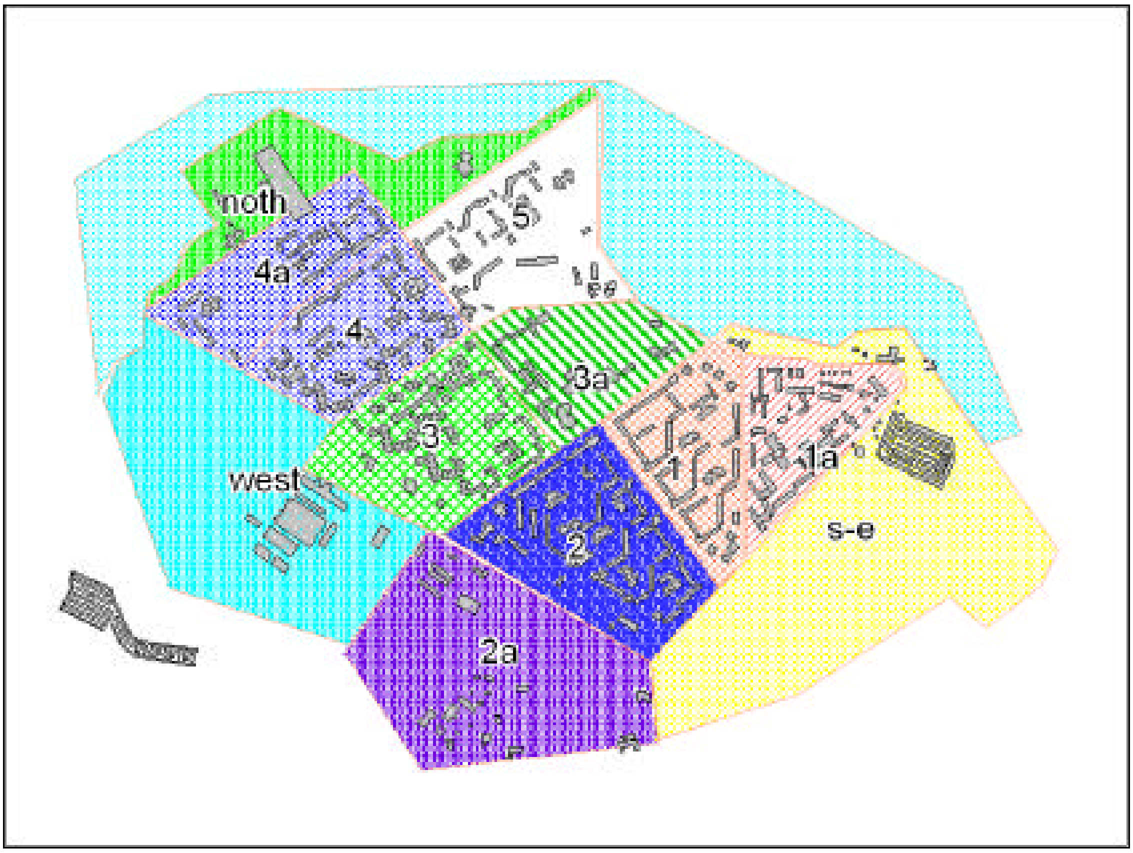


Figure II-2. - Map of microdistrict locations in the town of Pripyat.

In the course of constructing the town (in the 1970-80s) the local landscape and ecological conditions were considerably changed. The fact that trenches were several meters deep resulted in irreversible changes in lithologic and groundwater conditions. Light, sandy soils were reinforced with gravel mounds that were littered by construction waste. In this way, the site, which differed from the adjacent soil in soil texture and chemical characteristics, was formed. The following post-construction recultivation activities were added to these changes: filling a peat or meadow sod layer, using organic and mineral fertilizer, and artificial irrigation. As a result, a rather complicated pattern of soil-substrate conditions and vegetation cover has emerged.

Vegetation of the town is mainly represented by deciduous woods and bushes of artificial plantation (chestnut, lime, maple, poplar, locust, weeping willow, etc.). Almost all are of comparable age with the age of the corresponding microdistricts. The oldest vegetation was in microdistricts #1, 1a, 2, and 3: up to 15-20 years by the time of the accident. In new microdistricts #4, 4a, and 5, there were mostly young, newly planted trees. Within the residential area there are only two pine-tree plantations (in microdistricts #1a, 3), which were there before the town was built. Many more pine-tree plantations surround the residential area in the southeast, south and southwest outskirts (recreation area) (Figure II-5). Some southern plantations were 30-50 years old by the time of the accident, the rest, up to 20-30 years. There were many rosebushes and other bushes, and many flowerbeds and lawns. There were a few ploughed plots within the residential area (traditionally, flowerbeds and small plots around the trunks of trees). Fallen foliage and grass were always taken away before the accident (commonly, in April).

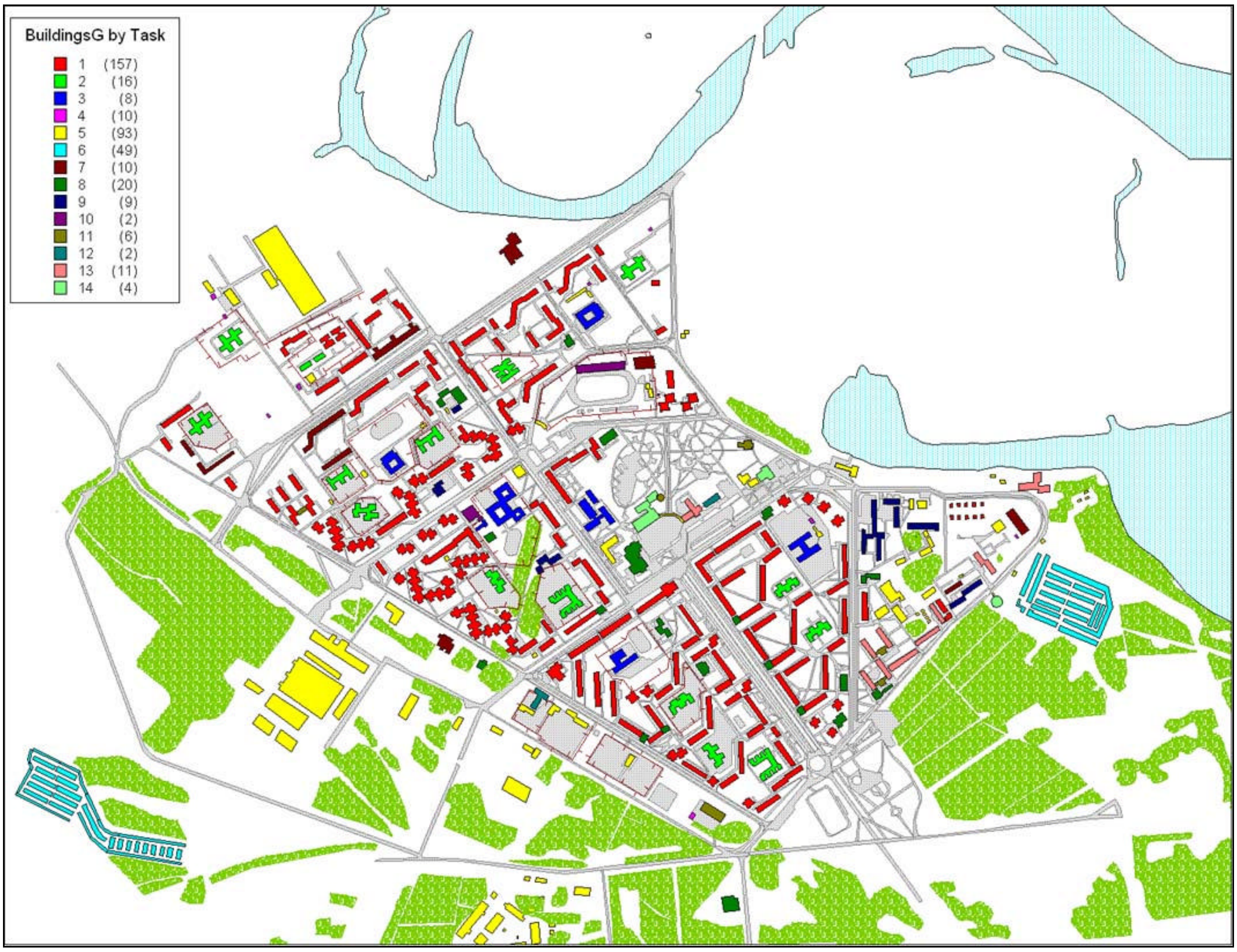


Figure II-3. – Schematic map of town Pripyat (vector layers).

It is very important to note that, by the end of April 1986, deciduous trees and bushes had only just begun to open their leaves, while the pine-tree plantations had very developed surfaces for adhesion. However, during the 10-day acute period of the accident, all leaves were opened and were able to capture radioactive fallout [Chernobyl, 1990].

After the population was evacuated, natural transformation processes of vegetation cenosis began (Figure II-6). Under conditions of the absence of human care, former lawns, flowerbeds, play-yards and other open plots were transformed to meadow-like areas, and wood plantations to semi-forest areas. Forest litter began to form under the canopy of trees and bushes, and juvenile soil on waterproof surfaces of roads and footways [Tyutyunnik, Bednaja, 1998]. Humidity has increased in most of the forest districts.

Building types

In the town there are mainly multistoried residential buildings (5-16 storied). The old microdistricts (#1, 1a, 2) have mostly 5-storied buildings, while microdistricts #3, 3a, 4, 4a and 5 have almost all 9-storied ones (Figure II-7). Only 7 buildings have 16-storied height. The buildings of 1-3 stories were used for different public purposes (schools, kindergartens, hospital, clinics, theaters, sports, shops, etc.) or for services and facilities (municipal, instrument-making plant, greenhouses, transport parks, laundry, garages, etc.) (Figure II-8).

Figure II-4. – Airplane images of Pripyat (1992).

There are approximately 400 buildings total, located in the town and out on the surrounding area (55% are residential; 13% are schools, kindergartens, hospitals, etc.). Some buildings belong to the surrounding area, outside of the town circle.

Almost all buildings have plane (flat) roofs, waterproof external surfaces, and external balconies. Most of buildings are constructed from large or medium size concrete blocks; some are constructed from bricks and finished by ceramic tiles. The town had a district heating, water and power supply.

Table II-1 summarizes the buildings by height. The supporting files accompanying this scenario include a data base of buildings. The data base includes the height of buildings and the number of stories (floors) in the buildings. This makes it possible to make a 3-dimensional model of the town, which can be useful for modelling the initial redistribution of radionuclides through compartments of the town. Figure II-9 compares photographic and three-dimensional images of the town.

Figure II-5. – Image of forest-stand, located on the southeastern side of town (closest to ChNPP), 2003.

Table II-1. Structure of the town constructions, by height of building (m).

	height, m			
	Mean	Min	Max	%
1-2 stories	4.4	2.5	6.0	11.0
3-4 stories	9.5	6.8	13.9	19.6
4-5 stories	16.3	14.0	20.9	28.2
9 stories	28.0	26.1	33.0	35.4
16 stories	44.3	39.0	47.7	4.3

Figure II-6. - Modern state of plants in the town of Pripyat.

Population and activities

In April 1986 the town had 49,360 people (including approximately 17,000 children), and the population density was approximately 10,000 people per km^2. A considerable part of the adult population was busy in operative, service and management works at the Chornobyl NPP. Many people worked at the building sites of the town and new power-units. There were 5 schools (plus one was being built), 1 technical school, 16 kindergartens, and one large hospital complex. Many people were busy with municipal and transport services and in trade.

Contamination

As a result of the Chornobyl accident, the Pripyat urban area was contaminated many times, by different sources, and very heavily altogether. Still now the level of contamination of the town remains increased, in comparison with natural background, especially with respect to the content of transuranium elements.

According to the data of a Chornobyl meteorological station, during the first nights after the accident there was almost still weather at the surface layer of the atmosphere, while at upper layers there were west and northwest prevailing winds. In April 26, 1986, radioactive fallout was deposited mainly in the southern district of the town, which was sparsely populated with a railroad station and a market, and the adjoining settlement Yanov and lawn-and-garden plots of Pripyat residents. The heavy constituents of the radioactive releases (explosion products) were deposited on industrial and forest areas, nearest to the unit. Also, this day and in all subsequent days, radioactive ‘dirt’ was brought into the town by transport and people, creating local irregular contamination. During the day of April 26, radioactive releases

a) Typical 5-story buildings (apartments).

b) Typical 9-story buildings.

c) Kindergarten.

d) Dormitory.

Figure II-7. Typical types of apartment and other residential buildings in Pripyat.

a) Shop.

b) Administrative center of Pripyat (restrain, culture center, hotel, administration building).
Figure II-8. - Main types of other buildings in the town.

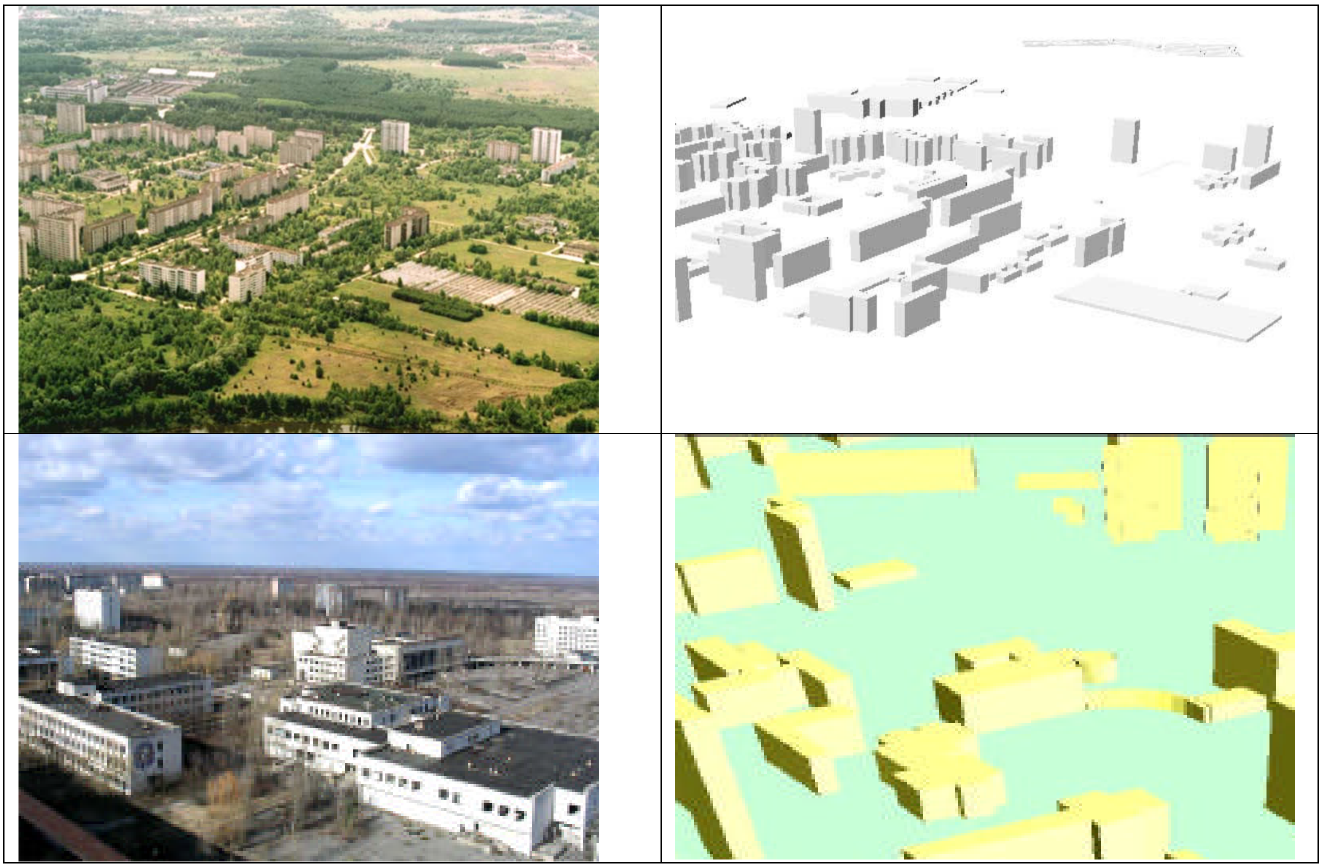


Figure II-9. – 3D model of town.

continued to be transferred to the west and southwest, passing Pripyat. The radiation level in the town was about 0.014-0.13 R/h [Chornobyl catastrophe, 1997]. By noon of April 27, the wind had changed and was directed to the eastern outskirts of Pripyat. The exposure dose rate quickly increased up to 0.4-1.0 R/h, and in some places, 1.5 R/h (by other data, up to 4-7 R/h [Repin, 1995]). During the period of 14:00-16:30 all of the town's residents were evacuated. The main radioactive precipitation fell out on the town during April 27-29. All fallout was dry and contained many 'hot' particles (finely dispersed fuel and reactor constructional materials). Thus, the most strongly radioactive fallout occurred along the southern and eastern outskirts of the town. A meteorological data set for the first days, up to the end of June, with a step of 6 hours, is presented in the supporting files (see Annex II-1 for a list of supporting files).

The first observation point network was established by ChNPP radiation protection service officers. These data included 26 points located in the town Pripyat (Figure II-10). There are four sets of data: 26.04 12:00, 26.04 24:00, 27.04.12:00, and 27.04 17:00. On the basis of these data, the Government Committee made the decision about evacuation of the town's population, which formally was accepted about 12:00 27.04.

During the summer of 1986, some dosimetrical surveys were done in the town by a team of students from "Gorkiy Polytechnic Institution", department of radiation safety. These students were involved in activities directed toward liquidation of the consequences of the Chernobyl catastrophe on the temporal principles. They were doing measurements in some local areas of the Zone (especially in the town of Pripyat) during the summer of 1986. There

Figure II-10. – Reference network of radiological observations in Pripyat during the first few days.

are some available sets of data from this team, but the notes from this expedition have not been located.

During Autumn of 1986, a lot of decontamination work was done in the town by military forces (especially by the so-called Chemical forces of the USSR). During decontamination exercises, some additional work for evaluation of the total radiological state of the town was done. Some data reflect the activity in the one of most contaminated places of the town, a dormitory complext in district #1. Data from this observation are presented in a separate file (see Annex II-1).

Many years later, some scientific surveys were done in the town. These surveys include: a small permanent observation network of the Dosimetric Service Enterprise of the Administration of the Exclusion zone; one point of automatic system of control of radiation situation (concentration in the air); and some detailed surveys by scientists of the Department of radiology and recovery lands. At the moment some data are available for the period of 1996-1999, which were obtained by all mentioned sources (see Annexes II-1, II-2).

Decontamination of Pripyat and surrounding areas
Decontamination of the town was done in two stages. During the first stage (May-June 1986), all buildings, roads and trees were washed using a fire-hose (nose-piece) and a surface-active additive. Also, road surfaces (asphalt, concrete, etc.) were treated with clayey solutions, which afterwards were simply washed. At the same time the river bank levees were created

along the northeastern and northern border of the urban area. During intensive decontamination, plugging of industrial and storm sewage was performed to avoid radioactive materials draining into the Pripyat River. During the summer of 1986 the streets of the town were regularly treated with dust-suppression techniques.

The first decontamination work in the town of Pripyat was carried out hurriedly in the beginning of May 1986 (few days) on a small area opposite the hotel ‘Polessje’, where the Government Committee was staying during the accident’s active phase. The work included washing of areas and buildings, and removing of some lawns.

Some days later (11.05.86) a decision was made to conduct test decontamination of some buildings. In 14.05.86 the first three buildings in micro-district # 4 were experimentally decontaminated to define a more successful method of the decontamination [Karataev et al., 1989a, 1989b]. There were kindergarten #11, residential houses Heroyev Stalingrada Str. #1, and shop #17. The distribution of contaminationof these buildings is given in Tables II-2 and II-3. The best results were given by water-jet methods (fire-hose, with or without additive surface-active substance of trade mark ‘SF-2U’). The decontamination coefficient for concrete surfaces was approximately 20 times, for other surfaces, 10-100 times. The flat ruberoid roof remained almost as dirty as before treatment, and needed to be intensively cleaned by brushes. Adjoining asphalt covers were cleaned up to background level. Using this experience, 70% of residential buildings and adjoining areas (roads, vegetation) were washed by the end of June 1986.

Table II-2. Contamination of the building surfaces in Pripyat, 12.05.86 [Karataev et al., 1989b].

Location	beta-particles/cm^2 min, n × 10^3
External horizontal surfaces	
concrete (road cover)	1000
concrete (blind area at the foot of building)	800
iron, painted	1500
iron, galvanized	800
bitumen roof cover	600
wood, painted	150
External vertical surfaces	
wall plaster, painted	800
wall plaster with granite bits	150
wood, painted	70
window glass	9
ceramic tile	100
Internal horizontal surfaces	
wood, painted	10
glaze tile	100

Table II-3. Contamination of the building surfaces in Pripyat, 12.05.86 [Karataev et al., 1989a].

Location	beta-particles/cm^2 min, n × 10^3
Kindergarten # 11	
Concrete wall, external surface	1000
Window frame	7
Painted metal stairs	more 1000
Wall internal (ceramic tile)	5
Window glass	9
Concrete floor	800
Galvanized iron of window ledge	200
Wall external (ceramic tile)	100
Bitumen roof cover	600
House Geroyev Stalingrada, 1	
Window frame	4
Floor in stairwell (ceramic tile)	500
Concrete floor	800
Concrete wall (internal)	7
Concrete wall plaster with granite bits	20

The next stage began in September 1986, and included total decontamination of some areas. During September 3-20, the western and central part of micro-district # 4 (including 9 residential buildings, two kindergartens, school, and future 2 dormitories for accidental staff; Figure II-11) were decontaminated [Karataev et al., 1989b]. The decontamination coefficient of glaze surfaces was approximately 160 times. The brick surfaces and relief wall plaster had the lowest decontamination coefficients (10 and 15, respectively). Intensive treatment of roofs using washing and brushes gave 10-20-fold results. Ground areas were decontaminated by bulldozer removal of the 10-15-cm upper soil layer (9.9 ha total): the radiation level dropped from 20-40 to 3-7 mR/h, and after additional manual cleaning, up to 0.7-2.2 mR/h. On a plot, when decontaminated ground was covered up by clean sand (5-10 cm layer), radiation reached 0.3-0.7 mR/h. Damaged ground surfaces were treated with silicate and vinyl compositions. Interior apartments of the buildings were decontaminated too.

Dust-suppression technologies included an application of technical lignosulphates (TLS) for ground areas (land or air spraying), and oil tailings for road surfaces (land spraying) [Patrilyak et al, 1989.]. These works were carried out in May-October 1986, on the town's territory and surrounding areas (including sand plateau, 'red forest' and industrial area). Due to the decontamination works, the average exposure dose rate in the town in December 1986 dropped to 2.8 mR/h, while without their performance it could be about 20-40 mR/h [Zykov et al., 1989].

The same activities were expanded to areas of micro-districts #4a, 3a, and 2a in 1987.

Decontamination of the town of Pripyat was carried out to provide convenient conditions for work and rest for the accidental staff. The following buildings and working areas were restored: Special Enterprises 'Complex' (former building of city administration and some others), Enterprises 'Cpecatom' (former instrument-making plant 'Jupiter'), Department of dosimetry control (buildings of former technical school, and Lab of external dosimetry),

Figure II-11. Dormitory where personnel were living in 1987-1990.

scientific organizations (former kindergarten, greenhouses and adjoining technical area in district #4a), department of town's communication, water-cleaning plant and transport parks (districts #2a and 3), special laundry (district #1a), telephone office center (town's center), police department (district #2a), and some others. In total, up to 22 buildings were restored. Decontamination works took place on 246 ha; there were cleaned up to 110 000 m^2 of the building outdoor surfaces and up to 13 000 m^2 of roofs. Up to 100 000 m^3 of contaminated upper soil layer were removed, and 144 000 m^3 of clean sand were brought in. All restored buildings and areas were provided with heat and electric power from Chornobyl NPP, and water from deep wells. Water cleaning and sewage constructions were also restored.

Since 1988 decontamination measures in the town have been carried out occasionally and in restricted areas, but dust-suppression washing of the streets was continued regularly in arid seasons at least 10 years after the accident.

Some areas surrounding Pripyat to the east, south and southwest were totally decontaminated in 1987–1989 also, to eliminate sources of secondary contamination of the town and to decrease the dose burden on the accidental staff. These areas were: sand plateau (to east, close to the town), "red forest" and industrial area (to south, 1.5-2 km from town), and former railway station settlement 'Yanov'. In 1986 only dust-suppression technologies were used, based on land or air spraying of technical lignosulphates (TLS) and oil tailings for road surfaces (land spraying) [Patrilyak et al., 1989]. In the spring of 1987 a new technique of land fixation was tested on a plot of the sand plateau. A mixture was sprayed: some kind of latex, peat pellets and cereal seeds (including oats) [Mesyats et al., 1989]. During April-June 1987 almost all areas around the Chernobyl NPP and Pripyat were treated by this method. A new technique included an application of TLS and cereal seeds, together with a thicker peat layer (3-5 cm) on damaged surfaces. The center of the town of Pripyat was treated by this method [Shilin et al., 1989]. Use of both methods gave an unstable effect: some areas did not get surface layer fixation.

In September 1987 the next technique was applied. The damaged surfaces were treated by TLS and ground limestone, then it was ploughed; seeds of wild cereals were sowed together with winter rye, and then the ground was additionally treated by TLS [Patrilyak et al., 1989]. This also gave unstable results. Later the area of former ‘red’ forest was additionally planted by bushes and trees (1988-1990). The grass cover inside Pripyat districts (damaged by decontamination works) was restored also. However, the sand plateau still remains without grass and wood vegetation, and its surface layer is only partially fixed by poor moss cover.

Due to the countermeasures on soil fixation and dust-suppression, air contamination was decreased by ten times already in the summer of 1987 [Mesyats et al., 1989]. Since July 1987 air contamination in Pripyat’s district #4 did not exceed 18.5×10^{-2} Bq/m^3 [Bakin et al., 1989.]. By other data, air radioactive deposition in the town in the summer of 1987 was: 37-74 Bq/m^2 per month (^{137}Cs), total concentration of beta-emitting radionuclides in air was approximately 10^{-5} Bq/m^3, alpha-emitting radionuclides, 10^{-7} Bq/m^3 [Zykov et al., 1989]. In 1987 the main contribution to the value of the exposure dose rate in Pripyat was provided by ^{144}Ce and ^{134,137}Cs, with a gradually increasing fraction of ^{137}Cs (See Table II-4). The radionuclide concentration in air at the two automatic radiation control posts (‘Stadium’ and Lab of external dosimetry) during 1989-1991 period is given in Table II-5.

As a result of the countermeasures, the contamination of the urban area as a rule increased in order: road surface, roadside, adjoining territory (Table II-6). Radionuclide concentrations in air over the roads were considerably higher than at distant plots (in Pripyat, up to 130-180 times, comparing roads and radiation control posts, which are 50-200 m from each other).

As a result of removing the original upper soil layer and without application of fertilizers and new humus soil, the decontaminated areas have a peculiarity of low radionuclide binding. On the decontaminated depletion areas, ^{90}Sr and ^{137}Cs migrate down and transfer to vegetation more intensively [Baryakhtar et al., 2003].

Unfortunately detailed data about some places of decontamination works are practically absent, and it is not possible at the moment to reconstruct all of the detailed information about decontamination work in 1986. Some data possibly are available via former colleagues, who at the moment work in Russia, in Moscow.

Table II-4. Contribution of different radionuclides to the value of the exposure dose rate in Pripyat, % [Prokopenko et al., 1989].

Date	^{134}Cs	^{137}Cs	^{144}Ce	$^{95}Zr+^{95}Nb$	^{106}Ru	Dose rate, mR/h
01.08.87	21.2	27.6	23.3	12.2	15.7	1.0
01.09.87	21.1	29.5	23.2	9.3	15.9	0.93
01.10.87	22.8	31.3	22.8	7.2	15.9	0.88
01.11.87	23.4	33.0	22.3	5.4	15.9	0.83
01.12.87	23.8	34.5	21.4	4.1	15.7	0.79
01.01.88	24.3	36.0	21.1	3.1	15.5	0.76
30.06.88	25.3	43.9	16.8	0.5	13.5	0.62
31.12.88	25.0	51.0	12.7	0.1	11.2	0.52

Table II-5. Air contamination in the town of Pripyat in 1989-1991, n × 10^{-6} Bq/m^3 [Demin et al., 1992].

Date	Stadium			Lab of external dosimetry		
	^{137}Cs	^{90}Sr	$^{239,240}Pu$	^{137}Cs	^{90}Sr	$^{239,240}Pu$
01.1989	363	103	2.1	2553	588	11.8
02.1989	1369	533	10.7	3034	940	18.9
03.1989	518	225	4.6	2923	722	14.5
04.1989	2035	1032	20.9	740	2261	45.9
06.1989	999	317	6.4	44400	10286	208.3
07.1989	407	168	3.4	3700	1125	22.8
08.1989	407	68	3.7	2701	907	18.5
09.1989	285	58	1.2	4810	1047	21.3
10.1989	204	34	0.7	1665	426	8.7
11.1989	211	67	1.4	2257	108	2.2
12.1989	70	25	0.5	4070	751	15.4
01.1990	167	56	1.1	888	155	3.2
02.1990	181	94	1.9	3700	1872	38.5
06.1990	925	334	6.9	12580	1787	36.9
11.1990	25			629	102	2.1
12.1990	241	83	1.7	814	330	6.9
01.1991	196	118	2.5	2257	1036	21.8
02.1991	159	96	1.3	1480	255	5.4
05.1991	174			1295	168	3.6
06.1991	352	212	4.5	1184	95	2.0
07.1991	200	53	1.1	1147	422	9.0
08.1991	237			1036	1140	24.3
09.1991	148			777	198	4.2
10.1991	444	124	2.6	555	34	0.7
11.1991	137			222	31	0.7

Table II-6. Average level of road contamination in 1986-1991 (β-particles/cm^2 × min; γ μR/h) [Demin et al., 1992].

Period	Road cover		Roadside		Adjoining area	
	β	γ	β	γ	β	γ
May 1987	-	1800	-	6400	-	33100
June 1991	105	81	314	154	-	-

ANNEX II-1
List of available information for Pripyat

#	Information	Directory/File(s) name
1	Text of description of Pripyat situation	Main Text
2	List of information (this annex)	Annex II-1
3	Description of vector map layers	Annex II-2
4	Raster map of the Pripyat and surrounding areas (about 5 km) including ChNPP locations. This map is raster copy of 1:100 000 map of 1986 publishing.	Pripyat100.jpg
5	Electonic (vector) map of Pripyat and surrounding areas (about 2 km), scaleable, set of MapInfo files, files with similar name create layers. (set of 9 layers, 38 files)	MapPripyat/*.*
6	Electronic (vector) map of Pripyat and surrounding areas (about 2 km), scaleable, set of MapInfo MIF/MID files, pairs of files with similar name create TXT description of layers, MIF is geographical description, MID is data contents. (set of 18 files)	MifPripyat/*.*
7	Radiological vector layers set of data, which described development of situation in the town. (set of 8? layers, 32? files)	DataPripyat/*.*
8	Meteorological data with 3 hours step, from 26.04.86 00:00 up to 30.06.86 received from six stations, located around Chernobyl Zone on Ukrainian territory	Meteo/Weather86.xls
9	Meteorological data, averaged (or cumulative) to monthly step, from 07.1986 up to 12.1998, Chernobyl meteostation	Meteo/ChernMonth.xls
10	Decontamination work in Pripyat, one MS Word file (Annex II-3) with description and explanation and set of files (one layer) of MapInfo	Decontamination/*.*
11	Information about contamination of buildings in #1-microdistrict in 1986 (October)	Dormitory86/*.*

ANNEX II-2
Description of vector map layers for Pripyat

All vector layers were created using different version of MapInfo, but all layers after creation has been adapted to the MapInfo Professional 7.5 CSP. (ESRI versions of most layers are also available.)

All layers are presented in projection longitude/latitude. This projection is a world degree projection and accords to USSR Gauss-Krueger 36 (6 zone) projection (should be converted to GK-6 meters zone), or WGS 84 international Mercator zone. All coordinate data are convertible to ArcView/ArcInfo via built-in translator. Other available format is *.MIF – MapInfo interchange format, which contains coordinates of all points of each object and data base related with each object (text format).

Geographical data (object's counters) were created manually on the basis of images, some raster maps, and paper plans. Mainly to make an e-map of the town we used the plan of town development, which was designed before the accident.

Some layers contain data sets; some layers have just geographical objects to help in understanding of town peculiarities.

Description of information (topo) layers of vector map of Pripyat.

Layer "BUILDINGS"

Name of column	Data type	Description of column
Name	Character 8	Label to make link between geo and data set
Id	Integer	ID of row, just number of object on order of digitizing, correction.
Area	Decimal	Area of polygon objects, sq. km calculated by internal function of MapInfo
Buildings Number	Character 8	This value is a unique number of buildings in the local description system. No relation to real post number.
Height	Decimal	Height of buildings (meters), made by direct measurement
Floor	Integer	Number of stories (floors) in buildings, made by visual estimation This value quit discreet, has less error than height. Ground floor is first floor.
Task	Integer	Type of building utilization (house, apartment, administrative, garage, etc.) 1 – Apartment houses: the people are in, basically 12 hours per day in the nighttime period. 2 – Kindergartens: 7 hours daily permanent staying of children under seven. 3 – Schools and technical school: daily staying of children from 7 to 17 years old during daytime hours. 4 – Electricity distribution buildings (not required permanent)

		5 – Technical tasks (enterprises, offices, storehouse, greenhouses, factories, boilers, water distribution, warehouses) 6 – Garages, special set of buildings, located out of town, constructed from metal or brick, connected to long, low, chains. 7 – Buildings, which had not been finished before accident. 8 – Shops, if separate, there are many buildings which have apartments and shop in one building 9 – Medical task, hospital, clinic, technical medicine buildings: laundry, pharmacy, boilers for clinics, etc. 10 – Sports areas buildings, swimming pool 11 – Restaurants, kitchens 12 – Administrative, municipal 13 – Hostel-dormitory, hotel 14 – Public houses (cinema, theatre, hall, library)
Wall	Integer	Wall material: 1-brick, 2-concrete blocks, 3-wood, 4-metal, 5-glass, 6-concrete coat, 7-mix
Roof	Integer	Material of roof cover: 0-no roof yet 1- metal 2- ruberoid 3- roofing slate 4- plastic 5-glass
Roof type	Integer	1 - flat 2 – sloping

All information data for layer “BUILDINGS” were created manually by digitizing on the basis of personal surveys in town, and on the basis of air images, different photos of Pripyat.

Layer “FOREST”

This layer reflects the geographical location of forested areas in and out of town, which were covered by old (big) forest, which can create a factor for radionuclide distribution and redistribution at the time of the accident. Basically that is pine tree artificial plantation which had age of 15-25 years at the time of the accident. Some southern plantations (southeastern outskirt, and close to Yanov railway station) were 30-50 years old. Inside the town vegetation is mainly represented by deciduous woods and bushes of artificial plantation (chestnut, lime, maple, poplar, locust, weeping willow, some fruit trees of former village of Semikhody). Almost all have comparable age with the age of the corresponding microdistricts. Weight of the deciduous trees was not too big in total, and it is not possible at the moment to separate coniferous and deciduous forest, possibly it will be done later. The layer was created on the basis of images, by manual digitizing.

Name of column	Format	Description of column
Name	Character 8	Contains character label to make link for any reason
Id	Integer	ID of row, just number of object on order of decreasing
Area	Decimal	Area of polygon objects, sq. km calculated by MapInfo
TypeF	Integer	Type of forest-stand, will be developed, deciduous, pine, bushes, etc.

Layer “HYDRO”

This layer presents geographical locations of watershed objects around the town of Pripyat, which include part of the former riverbed, and a few artificial ponds which are part of refinery system of town drainage.

Name of column	Format	Description of column
Name	Character (8)	Contains character label to make link for any reason
Id	Integer	ID of row, number of object in order of digitizing

Layer “ARTSURF”

This layer reflects the geographical locations of artificial ground surfaces: asphalt roads, concrete roads. Detailed description of different surface locations will be done in future work. This layer was created manually on the basis of a paper plan of the town and corrected manually using images and our own experience. Periodically this layer could not be made to correspond with real conditions because initially it was digitized from the plan of town development, but for modelling tasks it should be high enough quality.

Name of column	Format	Description of column
Name	Character (8)	Contains character label to make link for any reason
Id	Integer	ID of row, number of object in order of digitizing
Area	Decimal	Area of object, km^2, calculated by internal function of MapInfo
Surface	Integer	Should be a type of artificial surface, in developing

Layer NaturSurf

This layer reflects surfaces that are not covered by different artificial objects and by artificial surfaces, so as by forest, or by hydro objects. This layer was created automatically, by overlapping function of MapInfo. So, it is better to say, that this layer is a combination of lows, grass lands, etc. It is necessary to understand that this layer is: cover, from where was erased contours of buildings, contours of artificial surface, contours of hydro net, contours of forested areas, and contours of other objects.

Layer “FENCES”

This layer presents location of the different town fences: fences around kindergartens, around school yard areas, protecting some industrial areas, etc. Places of fence locations usually are associated with places of bush development, and after few years fences were “covered” by different kind of small trees and bushes. Fences in the town were usually constructed from metal or concrete railings; after the accident all the town area was fenced by barbed wire.

Name of column	Format	Description of column
Name	Character (8)	Contains character label to make link for any reason
Id	Integer	ID of row, number of object in order of digitizing
Material	Integer	In development
Height	Decimal	In development

Layer “SAND”

This layer corresponds to a sandy plateau (up to 5-7 m high and 90 ha in size), which was inwashed by the floodplain northeast of Pripyat for future building. At the moment of the accident, the sands had no surface fixation.

Layer “RoadOut”

This layer presents just the main road directions around the town. It has no meaning for modeling, rather information.

Name of column	Format	Description of column
Name	Character (8)	Contains character label to make link for any reason
Id	Integer	ID of row, number of object in order of digitizing

Layer “Mdistrict”

This layer presents contours of different microdistricts of Pripyat. Basically it accords with the administrative separation of the town. We added some more districts, which are around town; this is rather schematic-logical additional separation.

Name of column	Format	Description of column
Name	Character (8)	Contains character label to make link for any reason
Id	Integer	ID of row, number of object in order of digitizing
Mdistr	Character (8)	Marker of district
Area	Decimal	Area of object, km^2, calculated by internal function of MapInfo

Layers, which reflect dynamics of radiological situation

There are some data layers, which reflect the radiological situation at the moment of the accident, and development of the situation during the short term (within few months) and long term (up to 14 years) evolution.

Layer “ReperNet”

This layer presents data, which are based on the first dosimetric observations in the Chernobyl Exclusion Zone. According to available documents: “Initial data have been collected from the extensive network of referenced points, located on all the area of the 30-km zone and even out. Total amount of points were 122, within them there are 31 points located in Pripyat.”

Data for reference points of Pripyat were created from paper career, and include 26 available points.

Name of column	Format	Description of column
Name	Character (8)	Contains character label to make link for any reason
Id	Integer	ID of row, number of object in order of digitizing
26041200	Decimal	Dose rate in the point at the 26/04/1986 in 12:00, mR/h
26042400	Decimal	Dose rate in the point at the 26/04/1986 in 24:00, mR/h
27041200	Decimal	Dose rate in the point at the 27/04/1986 in 12:00, mR/h
27041700	Decimal	Dose rate in the point at the 27/04/1986 in 17:00, mR/h

Layers “IsolineNet86”:

This layer presents data of isolines of dose rate in the similar time with previous data set. I do not know how to describe it, rather it is picture, where lines are geocoded.

Layer “Grid_26_27_04_86”

This grid has been created by Surfer 7.0 function Krigging, on the basis of data, presented in two previous layers.

Name of column	Format	Description of column
Name	Character (8)	Contains character label to make link for any reason
Id	Integer	ID of row, number of object in order of digitizing
26041200	Decimal	Calculated dose rate in the point at the 26/04/1986 in 12:00, mR/h
26042400	Decimal	Calculated dose rate in the point at the 26/04/1986 in 24:00, mR/h
2704120	Decimal	Calculated dose rate in the point at the 27/04/1986 in

0		12:00, mR/h
2704170 0	Decimal	Calculated dose rate in the point at the 27/04/1986 in 17:00, mR/h

Layer “Point86Summer”

This layer presents data to dosimetric survey of the town by students team (see main document) in the summer of 1986. These GIS data were created by digitizing from the paper career, which was found many years ago. Unfortunately this document had no exact date of survey and later was lost, but according to our experience and taking into account that one of the former students from the team had been working in zone organizations, it is possible to suppose that these survey data reflect a period of measurements from the middle of June to the beginning of July. This decision has been done not only by experience, but by comparison of spatially distributed data from the set with some local data received by ourselves.

Name of column	Format	Description of column
Name	Character (8)	Contains character label to make link for any reason
Id	Integer	ID of row, number of object in order of digitizing
Doze	Decimal	Dose rate in the point (mR/h)

Layer “AeroGpoint”

This point presents results of air gamma survey which was done by helicopter survey in 1991. Each point presents the calculated value of ^{137}Cs density of contamination in the pointed area of 100 x 100 m. But original data was a spectrum of lines from 400 meters long continuous measurements by gamma spectral equipment. Methods and data of this survey are still not published and at the moment there re just restricted reports.

Name of column	Format	Description of column
X	Decimal	X coordinate, GK-6 (m)
Y	Decimal	Y coordinate, GK-6 (m)
Z	Decimal	Level of contamination by ^{137}Cs, Ci/km^2

Layer :”AirGgrid”

This layer was constructed by Surfer 7.0 (krigging method) on the basis of the previous layer data to create a uniform network via town and surrounding area with small size of grid (50x50 m).

Name of column	Format	Description of column
X	Decimal	X coordinate, calculated by software (m)
Y	Decimal	Y coordinate, calculated by software (m)
Z	Decimal	Level of contamination by ^{137}Cs, Ci/km^2

Layer “Point96_98Gp”

This layer presents data of dosimetric survey, which was done by us in 1996-1998. These data were presented in a report of the Chornobyl Scientific and Industrial Center for International Research in 1999. Data weres GIS coded by walking through the town and putting the point of measurement to the paper base. Later these points were digitized.

Name of column	Format	Description of column
Name	Character (8)	Contains character label to make link for any reason
Id	Integer	ID of row, number of object in order of digitizing
Doze	Decimal	Dose rate in the point _R/h
Date	Date	Date of measurement.

Layer “Point98GS”

In this layer are presented points where soil profiles (0-30 cm) were dug in 1998. These data were presented in a report of the Chornobyl Scientific and Industrial Center for International Research in 1999. It is possible to calculate the total level of contamination by ^{137}Cs in this point (kBq/m^2), so as to see vertical profile of radionuclide migration.

Layer: Point99_U

This layer presents data of a sampling and dosimetric survey of the town, which was made by a permanent network (there are similar sets for different years, still unavailable). Data contains information of dose rates (on surface and at 1 m height), and information about level of contamination (kBq/m^2), on the basis of 0-5 cm samples. Theoretically this layer (0-5 cm) still retained about 90% of the total stock of radionuclides.

Name of column	Format	Description of column
Name	Character (8)	Contains character label to make link for any reason
Id	Integer	ID of row, number of object in order of digitizing
DozeS	Decimal	Dose rate on surface (on soil) in the point (mkR/h)
Doze1	Decimal	Dose rate on 1 m height in the point (mkR/h)
Cs134	Decimal	Level of contamination by ^{134}Cs (kBq/m^2)
Cs137	Decimal	Level of contamination by ^{137}Cs (kBq/m^2)
Sr90	Decimal	Level of contamination by ^{90}Sr (kBq/m^2)
Pu238	Decimal	Level of contamination by ^{238}Pu (kBq/m^2)
Pu239240	Decimal	Level of contamination by ^{239}Pu + ^{240}Pu (kBq/m^2)
Am241	Decimal	Level of contamination by ^{241}Am (kBq/m^2)

Other radionuclides ($^{154,155}Eu$, ^{60}Co, ^{40}K) are presented in the table periodically.

ANNEX II-3

Layer description ‘Decontamination’

ID

Name:

Name	Description
Site 1	First three buildings which were decontaminated in May 1986 to test countermeasures
Site 2	Part of micro-district # 4, which were especially thoroughly decontaminated in September 1986.
Site 3	Area around green-houses. It was mostly decontaminated in September-October 1986. Area around a kindergarten was decontaminated in 1987.
Site 4	Dormitories in micro-district # 4, which were decontaminated in September 1986, and used for accidental staff during 1988—1994.
Site 5	River bank levee, constructed in summer 1986
Site 6	Area, which was ploughed in 1988
Site 7	Fence around micro-district # 4, built in 1987 in order eliminate uncontrolled movement of people and transport from contaminated areas into there.
Site 8	Wide area around industrial enterprises, including SE ‘Specatom’, SE ‘Complex’, water-cleaning plant, transport park, town’s communication department, Lab of external dosimetry, police, etc. It was decontaminated in 1986–1987 period.
Site 9	Area around special laundry, and some former dormitories, which were worked through methods of the town decontamination. Decontaminated in Autumn 1986.
Site 10	Central part of the town, including administrative building of SE ‘Complex’, Department of radiological control, and telephone office center. It was decontaminated in 1986–1987 period.
Site 11	Fence around the town of Pripyat, it was constructed in 1986.
Site 12	Sand plateau, which was treated in 1986 several times by dust-suppressioning substances. In spring-summer 1987 there were applied different techniques to fix sand upper layer.
Site 13	Areas to south and south-east from Pripyat, which were extremely contaminated, then strongly damaged in a result of decontamination works in 1986–1987, and then treated to restore soil and vegetation cover (1987–1990).

III. POLESSKOE

INTRODUCTION

Input data provided for this scenario include maps, DB tables characterizing the level of ground contamination, information on wind velocity, air temperature, precipitation, and photographs. Available test data for the contaminated area include concentrations of ^{137}Cs and a few data for ^{90}Sr, ^{134}Cs, ^{144}Ce, and ^{106}Ru. Additional information is also available, including the results of the projects ECP-4 and FGI Project 2/Sub-4

SITE DESCRIPTIONS FOR POLESSKOE (Longitude: 29,24 Latitude: 51,14)

Polesskoe town is situated at 53 km distance to the South-SW from Chernobyl NPP on the shores of river Uzh - right inflow of river Pripyat. Polesskoe district is the Ukrainian Poles'e. The landscape is plain, complicated in some places by eolian sandy hills and ridges, swamped areas, outcrops of crystalline rocks with a gradient in common in north-east. The region has a dense hydrographic network. Between 25 and 30% of the district is composed of forests, of which 80% is mixed oak and pine. The remainder of the district is composed of agricultural areas, settlements, villages, and roads. The main type of soil is soddy-podsolic sandy (dusty sandy), peaty soils. The climate is characterized as a moderate-continental. In the summer the least cloudiness is observed; however, in June – July, as the result of temperature inversions, storms and heavy showers are observed. In the summer, which begins May 21, the north-west humid winds predominate. The amount of atmospheric precipitation is given in Table 1.

Table 1. Quantity of precipitation*.

Month	Quantity of precipitation (mm)	Month	Quantity of precipitation (mm)
January	25	July	74
February	24	August	64
March	25	September	40
April	35	October	34
May	47	November	45
June	60	December	35

* BIOMOVS II. 1996. Scenario R: Atmospheric Resuspension of Radionuclides.

In September the amount of atmospheric precipitation decreases. The autumn begins on September 1-5 and goes on for 67-69 days; in this period the dry and warm south-west winds are observed. The winter begins on November 19 and ends March 14. February, March, and April have the highest average wind speeds. In March and April, the probability of a wind speed of 10-13 m s^{-1} at a height of 10 m is 7-8%; this corresponds to a wind speed of 5-7 m s^{-1} at a height of 1 m. Regional summaries of climatological data are given in Annex III-1.

The following maps are provided in Annex III-2:

1. B/1. Map of ^{137}Cs contamination in the settlement of Polesskoe (MBq/m^2) in September 1987;
2. B/2. Map of ^{90}Sr contamination of Polessky raion (kBq/m^2) in January 1998;
3. B/3. Map of ^{137}Cs contamination of Polessky raion (kBq/m^2) in January 1998;
4. B/4. A layout of the Polesskoe, 1st of May str., photographs of characteristic buildings;
5. B/5. A layout of the Polesskoe, Volia str., photographs of characteristic buildings;
6. B/6. A layout of the map of ^{137}Cs (kBq/m^2) contamination of Western cemetery and the Gorky str.

Type of deposition: dry and wet. Results of dose rate measurements above ground surface in the settlement of Polesskoe in 1986 are shown in Annex III-3 (similar data for 1990 are available for use as test data). Contamination density range of urban area is $5,6 \times 10^{11}$ - $3,7 \times 10^{12}$ Bq/km^2 by ^{137}Cs; the average value of contamination is $1,3 \times 10^{12}$ Bq/km^2.
The density of the radionuclide contamination measured at this site is given in Table 2.

Table 2. Density of soil contamination with ^{137}Cs (kBq/m^2).

Year	Minimum	Maximum	Average
1986	7,4	10189,8	1325,2991
1987	7,4	3437,3	854,7637
1988	555,0	555,0	555,0
1989	22,2	13878,7	1541,1966
1992	106,19	1134,05	375,6055

URBAN CHARACTERIZATION

Total area of the settlement: 22 km^2;
territory under the buildings: 2 km^2;
territory under kitchen-gardens : 5 km^2;

Conditions and characteristics of the buildings in the settlement:

Total number of private houses: 2882
average dimensions of them: (width) 5,6_m; (length) 7,0; (height) 4,5 m;
percentage of brick: 62,0;
percentage of wood: 28,0;
percentage of wood-brick: 7,5
other 2,5;
percentage of asbestos roofs: 90,0;
percentage of metallic roofs : 5,0;
other 5,0;
average value of the surface of private houses: 600 m^2;
average value of the surface of the gardens: 100 m^2;
average value of the surface of the streets near the private houses: 150 m^2

Total number two or more floors of the buildings: 8;
average values of their dimensions: (width) 10.0 m, (length) 32 m, (height) 12,4 m;
average value of the surface of the streets near the buildings: 1800 m^2

Total number of administrative buildings: 27;
average values of their dimensions: (width) 15,0 m; (length) 20,0 m; (height) 5,4 m;
average value of the surface of the streets near these buildings: 800 m^2

Total number of shops 5, only brick walls
average values of their dimensions: (width) 10,0 m; (length) 11,0 m; (height) 3,3 m;
average value of the surface of the streets near the shops: 500 m^2

In 1998 there were observed 2070 structures in Polesskoe. Of these, 72 are not habitable, including 26 administrative buildings, 5 institutions of education, 3 medical organizations, 3 cultural centers, trading centers, “Children’s peace” included as an example of operating centers, 3 enterprises of food, 3 enterprises of service, savings-bank, operating post-office, 3 enterprises of engineering service and 13 other organizations, as an example: operating branch of an Institute of Agrochemistry.

By types of building materials we can distinguish between the following:

- concrete-brick - 5,
- wood-brick - 74,
- concrete - 18,
- wood - 650,
- brick - 1322, including 32 of silicate brick.

Table 3 gives an example of the results of contamination measurements for a building.

Table 3. Example of the results for a contaminated building (1990).

Building Elements	Element areas, m^2	Average contamination Bq/m^2	Root-mean-square deviations, Bq/m^2	Measurements carried out
Roof sides:				
Northern	25	143.0	64.1	20
Western	20	29.3	14.0	15
Eastern	20	70.8	26.4	12
Southern	25	72.8	50.0	17
Building walls:				
Northern	36	9.7	6.0	18
Western	28	6.8	7.3	20
Eastern	28	9.0	5.4	22
Southern	36	5.6	4.9	20
Total				144

The results of measurements of the southern and eastern walls of a dwelling house are illustrated as an example. The diagrams of the cumulative sums (Figures 1-2; Tables 4-5) are applied to the results of measurements.

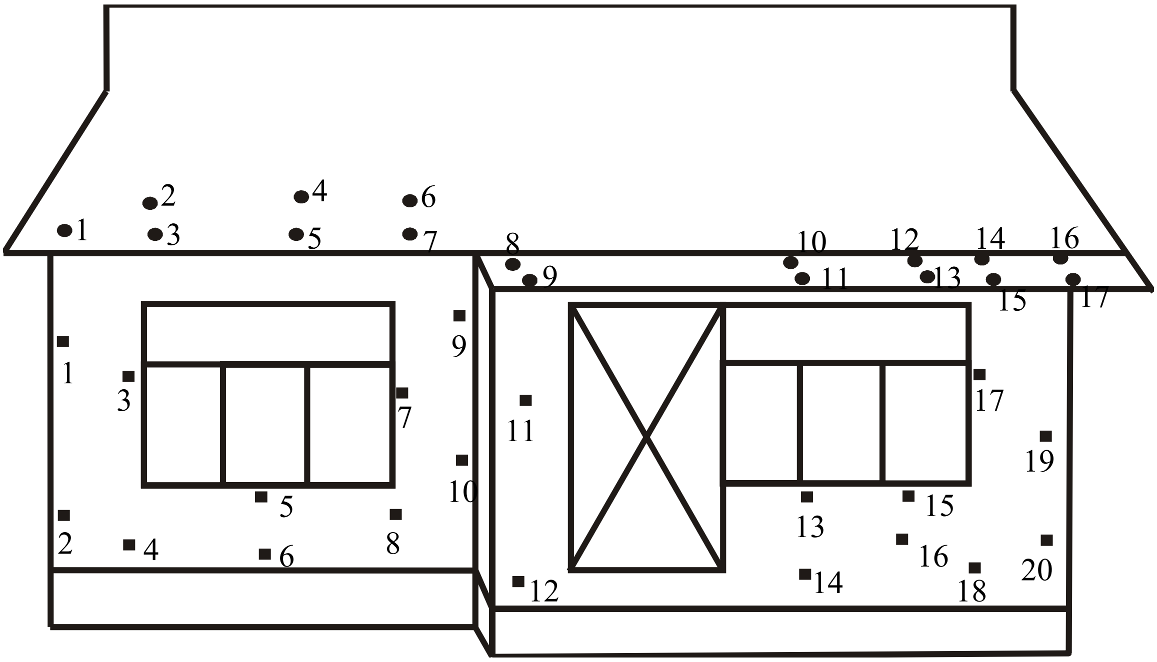


Fig. 1. Cartogram of the house, southern side measurement.

Table 4. Results and cumulative sums of surface contamination density on the wall and roof of the house, southern side.

Wall			**Roof slope**		
No. of point, h	**Contamination, kBq/m^2**	**Cumulative sums kBq/m^2**	**No. of point, h**	**Contamination, kBq/m^2**	**Cumulative sums, kBq/m^2**
1	0,9	0,9	1(21)	70,9	183,4
2	3,2	4,1	2(22)	69,4	252,8
3	13,8	17,9	3(23)	42,0	294,8
4	3,4	21,3	4(24)	56,1	350,9
5	11,7	33,0	5(25)	33,2	384,1
6	1,55	34,5	6(26)	130,4	514,5
7	1,9	36,4	7(27)	59,7	574,2
8	4,9	41,3	8(28)	245,3	819,5
9	5,1	46,4	9(29)	50,8	870,3
10	5,4	51,9	10(30)	52,4	922,7
11	3,4	55,2	11(31)	38,4	961,1
12	1,5	56,8	12(32)	80,7	1041,8
13	18,9	75,6	13(33)	50,8	1092,6
14	8,7	84,3	14(34)	56,1	1148,7
15	12,9	97,2	15(35)	93,3	1242,0
16	3,9	101,1	16(36)	53,9	1295,9
17	4,1	105,2	17(37)	53,7	1349,6
18	1,2	106,4			
19	1,2	107,6			
20	4,9	112,5			

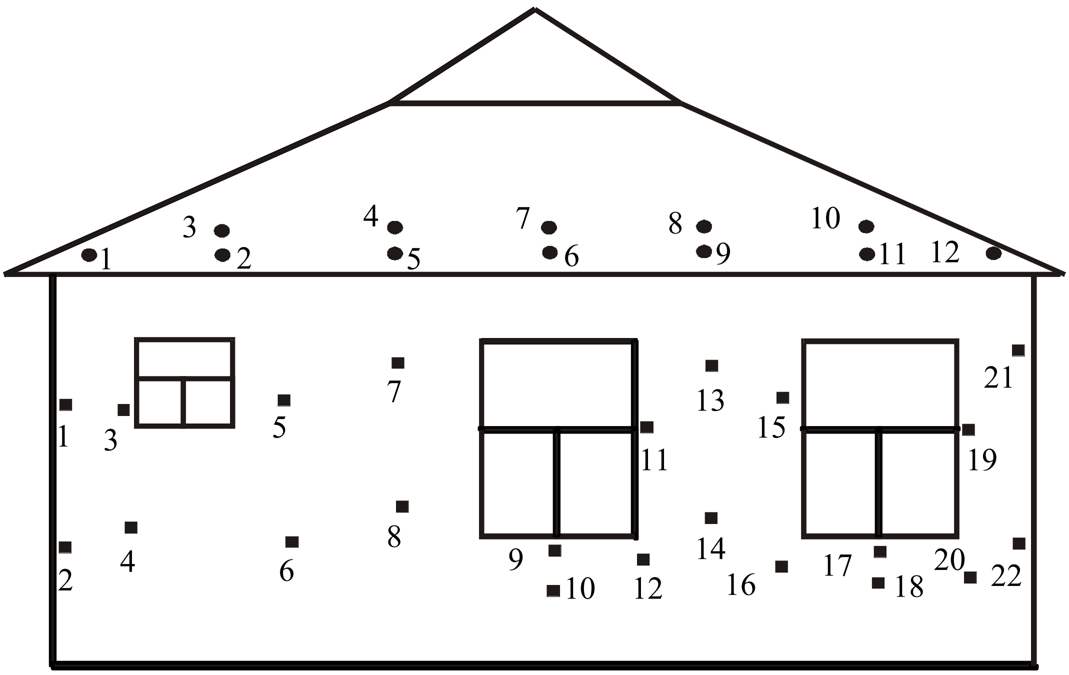


Fig. 2. Cartogram of the house eastern side measurement.

Table 5. Results and cumulative sums of surface contamination density on the wall and roof of the house, eastern side.

Wall			**Roof slope**		
No. of point, h	**Contamination, kBq/m^2**	**Cumulative sums, kBq/m^2**	**No. of point, h**	**Contamination, kBq/m^2**	**Cumulative sums, kBq/m^2**
1	2,9	2,9	1(23)	76,5	276,5
2	17,3	20,2	2(24)	123,2	399,7
3	7,5	27,7	3(25)	35,0	434,7
4	6,5	34,2	4(26)	54,9	489,6
5	6,3	40,5	5(27)	68,3	557,9
6	15,3	55.8	6(28)	108,8	666,7
7	8,3	64,1	7(29)	38,1	704,8
8	11,6	75,7	8(30)	45,4	750,2
9	14,3	90,0	9(31)	66,6	816,8
10	6,3	96,3	10(32)	79,7	896,5
11	12,8	109,1	11(33)	77,5	974,0
12	17,3	126,4	12(34)	74,5	1048,5
13	17,9	144,3			
14	14,1	158,4			
15	14,1	172,5			
16	6,5	179,0			
17	4,3	183,3			
18	6,1	189,4			
19	6,5	195,9			
20	0,7	196,6			
21	0,5	197,1			
22	2,9	200,0			

Migration in Construction Materials

Migration of radionuclides in construction materials, such as red and white brick, tiles and slate, and also wood has been examined. A typical distribution of ^{137}Cs in the thin outside surface layer (approximately 200 µm) of clay tiles is given in Fig. 3.

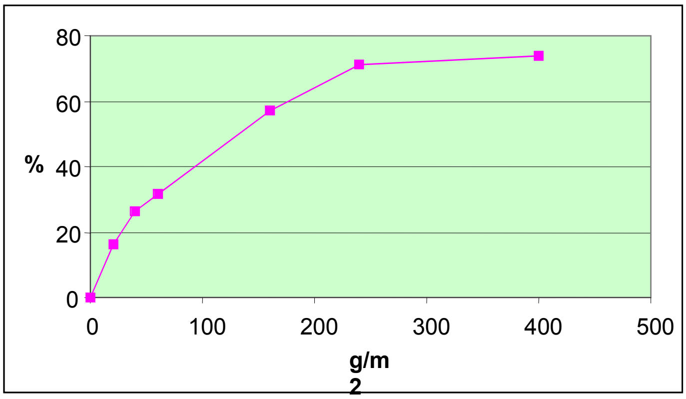


Fig. 3. Distribution of ^{137}Cs in a thin external superficial layer of a clay tile.

White brick features a thicker contaminated surface layer, with a thickness of 1.2 mm. This layer contains 80-85% of the absorbed ^{137}Cs. Note that the internal surface of the roof materials (clay tiling, slate, iron, wood chips, etc.) is also contaminated, though the value of this contamination is considerably lower.

The depth of penetration of contamination by ^{137}Cs measurement in 1995 was different for various building materials. Ninety five % of contamination was concentrated in the following layers:

- for the absocement slate, 0.1 - 0.3 mm
- for the tiles, 0.2 - 0.3 mm
- for the red brick, 0.3 - 0.5 mm
- for the white silicate brick, 0.5 - 0.8 mm
- for the rusty iron, 0.1 - 0.15 mm

Figure 4 shows the contribution of natural radioactivity to the specific activity of building materials.

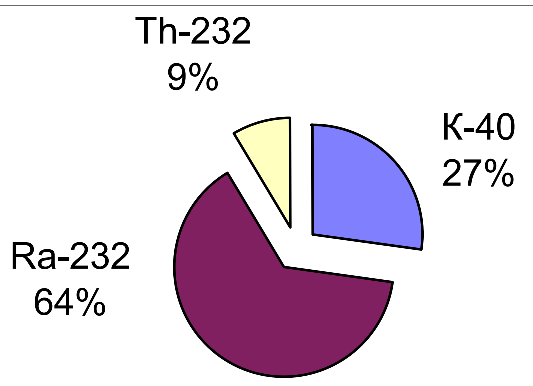


Fig 4.The Contribution natural radioactivity in specific activity of the building materials

PREVIOUS COUNTERMEASURES

According to principles of radiation safety, the decontamination must ensure a reduction of doses, radioactive contamination density and radionuclide concentrations in the air of inhabited places together with areas of the adjoining protective zone. In the early stages, when there were still many short-lived gamma emitters, the following were carried out on the most heavily contaminated land:

- removal of the top layer of soil on the most contaminated plots of land and in the places most frequented by people;
- decontamination of buildings;
- resurfacing (repaving) of roads, etc.

Decontamination works cost 28×10^6 rubles for 4 years (in scale 1990). In 1987-1990 there were the next countermeasures:
washing of walls, roofs, houses (2127 yards) - 95%;
removal of contaminated soils (450 yards – 3100 m^3) - 14%;
changing of roofs - 81%;
changing of fences (13.4 km) - 13%;
repaving of roads - 12%.
In 1987, 1560 workers using more than 90 units of technics made works of decontamination in Polesskoe.

RADIOLOGICAL CHARACTERIZATION

The population of Polesskoe in 1986 was composed of roughly 12100 people. Selected individual dose-metrical control executed in 1987 and 1989 has demonstrated that average values of external exposure yearly doses were correspondingly:
for children - 3,2 μSv and 1,6 μSv;
for adults, which were not engaged in agriculture production – 5,4 μSv and 2,5 μSv;
for agricultural workers - 5,8 μSv and 4,2 μSv.
Table 6 gives dose rates for ^{137}Cs activity measured in different locations in 1994. Tables 7-8 summarize information about the population.

Table 6. The exposure dose rate (μSv/h) activity of ^{137}Cs measured in 1994 in different locations of the settlement ranges.

Locations	Percentage %						
	Range of μSv/h						
	1,0-2,0	2,0-4,0	4,0-6,0	6,0-8,0	8,0-10,0	10,0-12,0	>12,0
House	36	61	3				
Yard		3	16	38	21	16	6
Shed	10	51	25	14			
Garden		10	24	20	7	20	35
Sidewalk	3	8	13	24	21	22	7
Street	8	11	35	30	8	6	2
Office	18	72					
Shop	20	80					
School	60	40					
Tractor station			100				
Field		80	20				
Forest		50	28	22			

Table 7. Distribution of the population in 1995.

Number of families	1077
Total number of persons	2838
Distribution in groups of population:	
infants < 1 year old	42
children 1- 16 years old	143
workers 16 - 50 years old	1164
pensioners > 55 years old	1605 (116 are working)

Table 8. Distribution of the population by activities.

Activities	Percentage %
Forest workers	0.8
Workers on experimental farm	1.1
Machine operators	0.5
Drivers and service personnel	6.7
Workers of auxiliary professions	4.9
Employees	12.2
Housewives	5.3
Children	6.5
Pensioners (except working)	52.4
At present time without work	9.7

The transfer factors of ^{137}Cs for the soddy-podsolic sandy soil and crops are as follows:

Crops and grasses	Transfer factor in m^2/kg
Winter rye, grain	0,22
Barley grain	0,11
Oats grain	0,12
Potato, tuber	0,20
Maize, green forage	0,50
Natural grasses	0,30
Improved grasses:	
Trefolium protense	0,54
Phleum protense	0,25
Dactilis glomerata	0,25

Transfer factor soil-milk for ^{137}Cs for soddy-podzolic sandy soil in 1994:
collective farm - 0.2 L/m^2
individual farm - 0.9 L/m^2

Information about remediation activities

According to the principles of radiation safety, decontamination must ensure a reduction of doses, radioactive contamination density and radionuclides concentration in the air of inhabited places and in the areas of an adjoining protective zone.

The necessity of separating decontamination works for populated areas is explained by the following reasons:

- Significant non-uniformity of radioactive contamination even within the borders of one individual farm;
- Variety of decontaminated surfaces within the borders of one object (roof, walls, fences, road covers, gardens, etc.);
- Presence of the population and industrial activity on decontaminated territories;
- Absence of experience with complex decontamination of populated areas;
- Absence of effective technical means of decontamination of the populated areas.

The industrial methods of decontamination and their efficiency can be compared with the methods used for decontamination of populated areas on purpose to fulfill investigations. However, one cannot help but notice that the significant volume of decontamination works executed in the inhabited locality for the first two years after the accident (1986-1988) by military junctions has shown their very low efficiency and economic weakness.

The experience of works after the Chornobyl accident has shown that decontamination of the populated areas must be carried out in a complex manner, using various methods for vertical decontamination (crowns of trees, roofs, walls of houses, fences) and horizontal decontamination (territory).

In estimating the significance of decontamination works, one should take into account, that reduction of radioactive contamination levels of objects can take place both due to decontamination and due to radioactive decay and such external factors as atmospheric fall-outs, air flows, etc. Also, it should be mentioned that it is impossible to evaluate the decontamination works without considering such measures, as dust removal and putting populated areas in good order.

Decontamination works in the Ukrainian inhabited localities

Tables 1 and 2 review the volumes of the complex works on decontamination that were carried out in the Ukrainian inhabited places during the period of 1986-1989.

Table 1. Volumes of both decontamination and dust-suppression works in the inhabited places in 1986.

Name of works	**Quantity**
Decontamination:	
Dwelling-houses and municipal buildings	22 570
Courtyards	over 1500
Schools and children's establishments	455
Stock-farm premises	about 300
Streets in the inhabited places, km	over 10 000
Removal of contaminated ground, m^3	over 300 000
Covering with asphalt for dust-suppression:	
roads, km	387
road-sides, km	37
territory (in Prypiat and Polissky), km^2	38 000
Treatment of roads and road-sides with dust-suppression materials, km	2377

Table 2. Volume of complex works fulfilled together with decontamination of inhabited places in 1986-1989.

Name of works	**Indications**
Replacement of roofs on houses and buildings	14077
Wrecking and disposal of ramshackle houses, buildings	2145
Replacement of fences, km	590
Decontamination of houses and within doors	7300
Decontamination of wells	2143
Transportation of contaminated ground and rubbish, th m^3	447,5
Delivery of clean ground, th m^3	312,3
Sanitary cleaning on the area, mln km^2	1,4
Building of hard-paved roads, km	567
Transmission line wiring, km	776
Water communication setting, km	570

Reduction of internal irradiation doses can be achieved mainly by Administrative-Organizing measures being carried out. It is possible to classify them as:

- Delivery of clean food products;
- Radiation control for the local food production;
- Cultivating of "steady" against the radionuclides in their mass accumulation products [provision of stable elements to reduce accumulation of the radioisotopes?];
- Inculcation of safe methods for growing, preparing and processing agricultural products received from personal farms.

Since all the actions for reduction of internal irradiation doses come to elimination of polluted food products from use and to radiation control of their quality, the main efforts ought to be directed toward decreasing external irradiation doses.

As a result of radioactive fallouts, spreading of the contamination had occurred for ecosystem elements and for inhabited and subsidiary constructions, roads, pastures, etc. These fallouts form the external irradiation dose.

Analysis of the radiation situation and dose loads for the population shows that choice of methods for decontamination and radioactive waste management are defined mainly by means of technical facilities available and by material and human resources balance. So the choice of decontamination technology presents by itself a compromise problem of minimizing two parameters: material outlay and risk for population health from remaining contamination of decontaminated territory.

Farmstead territory together with all complexes of buildings is taken as a conditional unit of populated area decontamination. Agricultural activity is a component part of human life; therefore to achieve radiation contamination control levels which ensure the possibility of getting products fit for food without limitations is the final goal of decontamination.

For yard subsidiary buildings and wooden barriers for farmsteads, if their contamination level exceeds the fixed level (Table 3) they are not subjected to decontamination. Instead, the intent is to replace them.

Replacing the roofs of dwelling houses and buildings attached to them is stipulated by the project for the condition of beta-activity exceeding more than 200 part/cm^2/min).

The most polluted areas of farmsteads are buildings for public use (farms, enclosures, workshops and others); the most polluted objects of public service are blind areas and drains.

According to the radiometric survey, some areas of farmsteads and kitchen gardens of public use in the villages were found as the most contaminated places.

The project provided in detail for removal by hand of contamination from blind areas around the houses and buildings of public use, as well as polluted soil places in some narrow parts, with further loading into containers. Soil and builders' refuse must be loaded from containers in the backs of cars and transported to LSWD (Local Site Waste Disposal) locations. Moreover, waste of organic origin is transported separately, since it is expected to require some different technology for its disposal.

Table 3. Control power levels from gamma-radiation exposure and surface contamination with beta-radiation radionuclides.

	Objects of contamination	**Level of contamination by beta-particles part./cm^2/min**
1.	Pre-school institutions for children, schools, medical and preventive establishments and equipment inside, food shops, enterprises of food industry and public food and equipment: Within the premises Territory and equipment	 20 20 50
2.	Objects of cultural-mass purpose, sport buildings and complexes: Within the premises Territory and equipment	 30 50
3.	Inner surfaces of dwelling premises and subjects of personal use	50
4.	Inner surfaces of service premises and outer surfaces of equipment inside	 50
5.	Open surfaces of the city territory and outer surfaces of buildings	200
6.	Transport means and mechanisms: Inner surfaces Outer surfaces Internal surfaces external surfaces	 50 100

On the completion of removal and transport of contaminated soil and materials from the courtyards and places of public use, ploughing ought to be done, or manual re-plough, if it is impossible for mechanisms to be fitted. Lime (5 t/ha, according to the calculation) is inserted simultaneously and potassium - phosphoric fertilizers (by 125 kg/ha) of each type.

The final stages of decontamination of populated areas included improvement of the farmsteads and places attached to them as well as places of common use, including delivery of clean soil for the blind area hollows, gravel (crushed stones) and asphalt for blind areas and courtyards, covering with asphalt, making barriers, recovering of roofs and taking down of constructions, grass sowing aimed at making a turfy layer on the places of common use, as well as turfing of waysides.

Decontamination of Soil

Dust particles, rain drops and flow, and contaminated leaves obey the principles of gravity which lead them to reach the soil at the final stage of natural transport. The soil around houses, yards, roads and pavements was found to be a significant contributor to the doses.

Skim and burial ploughing In the urban environment, the application of skim and burial ploughing would be restricted to large areas, such as parks. The plough skims off the topmost layer of soil (about 5 cm) and buries it at a depth of some 40-50 cm without inverting the intermediate layer. Hence the name 'skim and burial plough'. The removal of only about a 5 cm layer of topsoil rarely affects the fertility of the land, and poorer quality subsoil is not brought to the surface. Overall, the skim and burial plough greatly reduces radiation levels at the ground surface, the resuspension hazard is eliminated, most of the contamination is made inaccessible to plant roots, and soil quality is unaffected. The effect of the procedure, which has been tested in the former USSR, has been found to be a reduction of the dose-rate by some 94%, but in very sandy soils it may be difficult to achieve the objective with this method.

Triple digging Triple digging is an excellent method to reduce the dose to people, both where the uptake to plants is considered, and for external dose reduction. This method can be used in gardens and other places where it is impossible or expensive to use skim and burial ploughing. It can be seen that if the initial contamination is in the uppermost 10 cm of soil, then the dose reduction factor will range from 0.08 to 0.5, depending on the size of the plot and the initial distribution.

The sequence of decontamination work fulfillment will be dictated, as a rule, by the actual conditions of locality, by weather conditions, and it ought to be determined by the standard order for realization of decontamination works on populated areas. The order of priorities for works to be fulfilled is represented in Table 4.

Table 4. Sequence of decontamination work fulfillment

No.	**Name of works to be fulfilled**	**Order of work priorities**
1	Interim technological site setting-up in the populated areas for the road engineering to be localized, and determination of routes for the waste resulting from decontamination to be transported away	I
1	Decontamination of populated area 500-m protected zone	II
2	Decontamination of village inhabited area zone (except courtyards)	III
3	Fence disassembling	III
4	Roof dismounting	III
5	Pulling down of ramshackle and neglected buildings	III
6	Digging out of soil under the drains	IV
7	Digging out of soil with 40 mkR/hr exposure rate	IV
8	Cleaning of wells	IV
9	Infield spading by hand	IV
10	Infield ploughing	IV
11	Clean soil delivery	V
12	Setting up the blind areas	V
13	Courtyard covering with asphalt	V
14	Trimming of streets and inside roads with their planning simultaneously	VI
15	Digging out of radiation-contaminated soil along the streets and inside	VII

No.	Name of works to be fulfilled	Order of work priorities
	roads	
16	Ploughing of street surfaces, inside roads and adjoining areas	VIII
17	Accomplishment of streets (covering with asphalt and sod)	IX
18	Decontamination and re-cultivation of verified routes for the waste to be transported away	X
19	Assessment of radiation situation on the inhabited area territory	XI
20	The surface treatment with dust-coupling solutions	Operation is carried out before the work fulfillment

In the early stages, when there were still many short-lived gamma emitters, the following were carried out on the most heavily contaminated land:

- removal of the top layer of soil on the most contaminated plots of land and in the places most frequented by people;
- decontamination of buildings;
- resurfacing (repaving) of roads, etc.

Decontamination works cost 28 × 10^6 rubles for 4 years (in scale 1990). In 1987-1990 the next countermeasures were carried out:
washing of walls, roofs, houses (2127 yards) - 95%;
removal of contaminated soils (450 yards - 3100m^3) - 14%;
changing of roofs - 81%;
changing of fences (13.4 km) - 13%;
repaving of roads - 12%.
In 1987, 1560 workers using more than 90 units of technics made works of decontamination in Polesskoe.

Tables 5 and 6 summarize the volumes of materials remediated and waste removed during the decontamination efforts.

Table 5. The list of waste volumes at realization of decontamination-remediation works.

No.	Name of works	Volume of works		Volume of waste		Technical support
		units	quantity	units	quantity	
1	Contaminated soil 0,2 m depth to be taken away under the drains by hand	m^3/t	4798/6717	m^3/t	4798/6717	Means of small mechanization (shovels, barrows, containers, etc.)
2	Contaminated soil 0,2 m depth with ≥ 4,0 μSv/h), of exposure rate to be taken away Including by hand by cleaners	 m^3/t m^3/t m^3/t	 2383/3336 300/420 2083/2916	 m^3/t	 2388/3336	 Means of small mechanization Bulldozer. Loader pneumatic-wheel
3	Cleaning of the contaminated silts from wells by hand	m^3/t	34/61	m^3/t	34/61	Means of small mechanization (shovels, hoist, bins, barrows, containers, etc.)
4	Some separate plots digging out by hand (gardens, small fruit plantations, etc.) with introducing simultaneously: Chalk - 5,0 t/ha potash salt – 0,125 t/ha superphosphate - 0,125 t/ha	 ha t t t	 19,88 99,4 2,485 2,485			By hand
5	Surface treatment by 10% SSD solution when replacing the fences, digging out the soil, replacing the roofs, taking down ramshackle houses, ploughing (1,0 L/m^2 is a specific discharge of 10%-solution)	T	1800			Street-flushing car
6	Fence disassembling and setting	100 lm m^3/t m^2	226 1011/809 18705	m^3/t	1011/809	Auto-crane, Pneumatic-wheel loader
7	Roof dismounting	m^2/t	189/268	m^3/t	179/268	Auto-crane
8	Roof setting up	m^2/t	18705/266			Auto-crane
9	Pulling down of ramshackle and					Auto-crane,

No.	Name of works	Volume of works		Volume of waste		Technical support
		units	quantity	units	quantity	
	neglected buildings	m^3/t	70/56	m^3/t	70/56	Tip-lorry, bulldozer
10	Clean ground bringing	m^3/t	7181/10053			Tip-lorry, bulldozer
11	Blind area setting up Crushed stone delivery Asphalt delivery	m^2 m^3/t m^3/t	24350 2435/4357 730,5/1314,9			Tip-lorry, bulldozer, pneumatic-wheel roller, machine for covering with asphalt, hand road-roller
12	Covering courtyards with asphalt Crushed stone delivery Asphalt delivery	m^2 m^3/t m^3/t	35300 3530/6330 1059/1906,2			Tip-lorry, bulldozer, pneumatic-wheel roller, machine for covering with asphalt, hand road-roller
13	Infield ploughing for 0,3 m depth by T-4A tractor with introducing simultaneously: chalk - 5,0 t/ha potash salt - 0,125 t/ha superphosphate - 0,125 t/ha	ha t t t	81,85 413,85 14,52 14,52			Tractor, arrangement for additional fertilizing to be applied
14	Transportation of contaminated soils and building rubbish over 10 km distance	m^3/t	8475/11247			Dump-truck, dust-cart
15	WASTES Including organic waste			m^3/t m^3/t	8475/11247 1171/999	

Table 6. Decontamination of protected zone, territories for general use.

No.	Name of works	Units	Volume	Technical support
1	Ploughing of protected zone (500 m) 0,3 m depth by T-4A tractor (96 kWt) with introducing to soil: chalk - 5,0 t/ha potash salt - 0,125 t/ha superphosphate - 0,125 t/ha	ha t t t	270 1350 33,75 33,75	ULP-8 arrangement for additional fertilizing to be applied
2	Ploughing 0,3 m depth of territories for general use by T-4A tractor (96 kWt) with introducing to soil: chalk - 5,0 t/ha potash salt - 0,125 t/ha superphosphate - 0,125 t/ha	ha t t t	40 200 5,0 5,0	ULP-8 arrangement for additional fertilizing to be applied
3	Cleaning 0,2 m depth of reservoir-sides from contaminated soils (silts)	m^3/t	2480/3968	Tractor. Excavator pneumatic-wheel
4	Contaminated soil digging out 0,2 m depth from the ditches near roads	m^3/t	3660/5124	Excavator pneumatic-wheel
5	Transportation of contaminated soils to the point of waste disposal over 10 km distance	m^3/t	6373/9418	Dump-truck
6	Contaminated soil digging out 0,2 m depth and 1,0 m wide under the drains near the buildings of public use (farms, stock-houses etc.)	m^3/t	233/326	By hand (shovels, hoist, bins, barrows, containers and etc.)
7	Delivery and setting of soil layer 0,2 m depth for reservoir-sides and river-sides etc.	m^3/t	2480/3968	Dump-truck, bulldozer
8	Transportation of disassembled fences to the place of disposal over 10 km distance	m^3/t	332/266	Dump-truck
9	Road slopes sodding with grass-mix introducing	t	0,3	Seeding machine

The most radical way for reduction of exposure dose in the school and pre-school establishments is realisation of the decontamination process. Decontamination was made by removal of the top soil layer to the depth of 20 cm manually and with the help of a bulldozer. The removed soil was transported to be disposed of in the RW Disposal Point. The radionuclide content in this soil did not exceed 400 Bq/kg. In detail the technology of decontamination procedures for the schools and the volumes of fulfilled works are represented in Table 7.

Table 7. Technology of decontamination procedure for the schools.

No.	Operation	Unit	Number
1	Removal of the contaminated soil layer by hand	m^3	60
2	Removal of the contaminated soil layer by bulldozers and transportation for a distance of 10 m	m^3	131
3	Per extra 10 m	m^3	191
4	Loading of the soil into vehicles by excavators (0.25 m^3)	m^3	191
5	Transportation of the soil to the burial ground for a distance of no more than 5 km	ton	306
6	Uncontaminated soil exploitation by bulldozers in pits and transportation for a distance of 20 m	m^3	130
7	Loading of the soil into vehicles by bulldozers	m^3	130
8	Transportation of the soil for a distance of 1 km	ton	203
9	Strewing of the soil between trees by hand	m^3	40
10	Transportation of the soil by bulldozers for a distance of no more than 30 m	m^2	90
11	Vegetable soil exploitation by excavators and loading of the soil into vehicles	m^3	13
12	Transportation of the vegetable soil for a distance of no more than 1 km	ton	16
13	Strewing of the vegetable soil between trees by hand	m^3	13
14	Roller compaction of the soil	m^3	143
15	Mechanical land leveling	m^2	1190
16	Disassembling of asbestos-cement roof coverings	m^2	253
17	Replacement of asbestos-cement roof coverings	m^2	253
18	Loading of the roof coverings disassembled	m^3	5
19	Transportation to the burial ground for a distance of no more than 5 km	ton	6
20	Dosimetry	m^2	1419

Annex III-1

Regional summaries of climatological data.

date	timeMGT	airTemperature	atmPressure	windDirect	windVeloc
25.04.86	0	7,9	1024	90	1
25.04.86	6	13,3	1023	90	2
25.04.86	12	20,7	1020,3	120	3
25.04.86	18	16,9	1019,4	110	3
26.04.86	0	8,3	1019,8	0	0
26.04.86	6	14,2	1019,4	0	0
26.04.86	12	21,5	1017,8	115	2
26.04.86	18	15,3	1016,6	220	2
27.04.86	0	11,3	1015,8	0	0
27.04.86	6	13,7	1014,7	220	2
27.04.86	12	19,2	1012,5	145	2
27.04.86	18	13,8	1013,2	165	2
28.04.86	0	7,3	1013,1	0	0
28.04.86	6	8,6	1012,9	0	0
28.04.86	12	18,9	1011,1	220	1
28.04.86	18	14,7	1010,8	210	1
29.04.86	0	11,2	1010,7	170	1
29.04.86	6	13,6	1011	250	1
29.04.86	12	22	1010,3	225	2
29.04.86	18	17,7	1011,7	170	1
30.04.86	0	9,9	1013,5	0	0
30.04.86	6	15,2	1014,5	130	1
30.04.86	12	23,8	1013,3	120	1
30.04.86	18	19,7	1012,7	290	2

Total precipitation quantity of April: 35 mm.

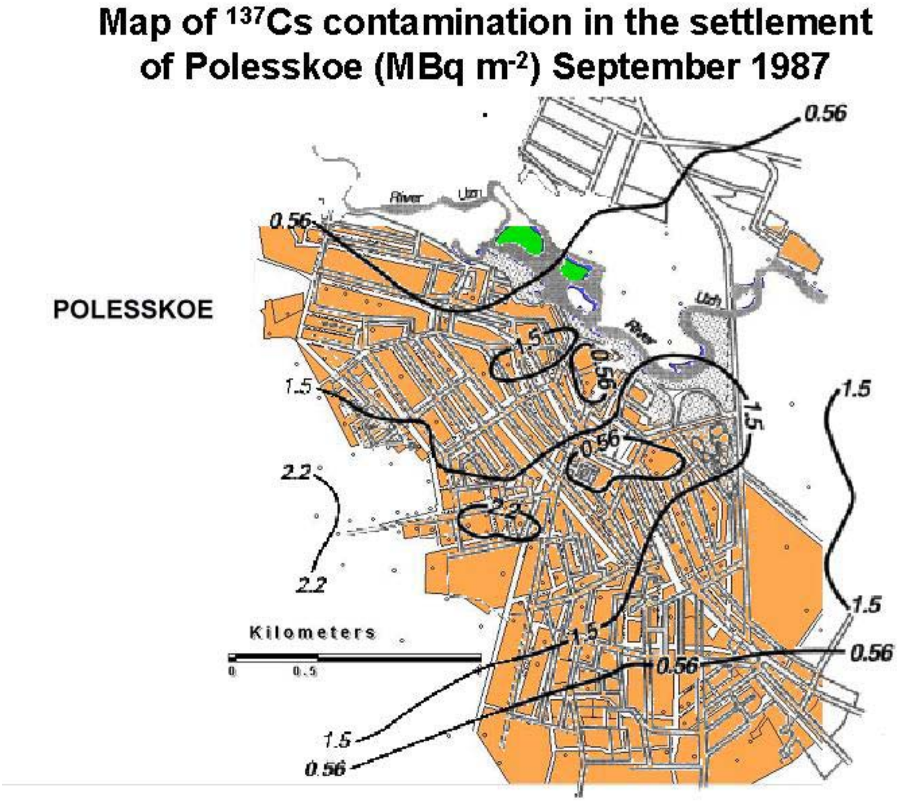
date	timeMGT	airTemperature	atmPressure	windDirect	windVeloc	precipQuantity
01.05.86	0	12,4	1013,6	285	1	
01.05.86	6	14,2	1016,1	360	1	
01.05.86	12	23,1	1013,7	330	4	
01.05.86	18	16,8	1013,9	350	3	
02.05.86	0	8,5	1015,1	235	3	
02.05.86	6	8,9	1014,8	350	3	
02.05.86	12	15	1012,9	350	7	
02.05.86	18	10,5	1014,3	30	4	
03.05.86	0	7	1014,9	355	3	
03.05.86	6	8,1	1015,2	30	5	
03.05.86	12	12,6	1014,8	30	5	
03.05.86	18	10,8	1015,2	25	6	
04.05.86	0	4,5	1016,2	20	2	
04.05.86	6	6,9	1018,4	30	4	
04.05.86	12	14,1	1017,5	30	6	
04.05.86	18	10,8	1018,6	40	5	
05.05.86	0	2,3	1021,1	30	1	

date	timeMGT	airTemperature	atmPressure	windDirect	windVeloc	precipQuantity
05.05.86	6	8,5	1022,1	235	2	
05.05.86	12	15	1019,7	35	4	
05.05.86	18	11,9	1018,1	290	2	
06.05.86	0	5,1	1019,8	30	1	
06.05.86	6	7,7	1022,6	60	2	
06.05.86	12	13,4	1021,9	60	4	
06.05.86	18	10,1	1021,8	50	1	
07.05.86	0	1,3	1023,7	300	1	
07.05.86	6	10,1	1026,9	360	1	
07.05.86	12	18,5	1023,7	90	2	
07.05.86	18	14,4	1022,9	200	1	
08.05.86	0	4,1	1024,2	0	0	
08.05.86	6	11,8	1024	325	1	
08.05.86	12	21,9	1021,2	150	2	
08.05.86	18	16,4	1019,4	280	1	
09.05.86	0	7,3	1019,2	0	0	
09.05.86	6	14,6	1017,4	50	1	
09.05.86	12	24,2	1015,1	60	2	
09.05.86	18	17,1	1015,2	75	3	
10.05.86	0	14,3	1015,4	0	0	
10.05.86	6	14,1	1016,1	75	1	
10.05.86	12	22,1	1015,9	90	2	
10.05.86	18	16,5	1017,6	315	2	
11.05.86	0	8,5	1018,8	0	0	
11.05.86	6	12,8	1019,3	310	2	
11.05.86	12	22,2	1017,2	280	2	
11.05.86	18	17,5	1016,4	230	3	
12.05.86	0	9,1	1016,1	0	0	
12.05.86	6	15,9	1014,7	255	2	
12.05.86	12	21,3	1012,2	295	5	0,3*
12.05.86	18	13,9	1014,3	290	3	
13.05.86	0	8,4	1016,4	295	2	
13.05.86	6	13,2	1017,5	315	2	
13.05.86	12	17,5	1018,2	270	2	
13.05.86	18	15,8	1018,4	280	1	
14.05.86	0	7,6	1020,2	0	0	
14.05.86	6	16,5	1021,1	60	2	
14.05.86	12	21,2	1020,8	40	1	
14.05.86	18	16	1020,8	0	0	
15.05.86	0	7,5	1019,7	0	0	
15.05.86	6	17	1019,6	100	1	
15.05.86	12	24	1017,9	170	2	
15.05.86	18	19,3	1017,6	150	1	

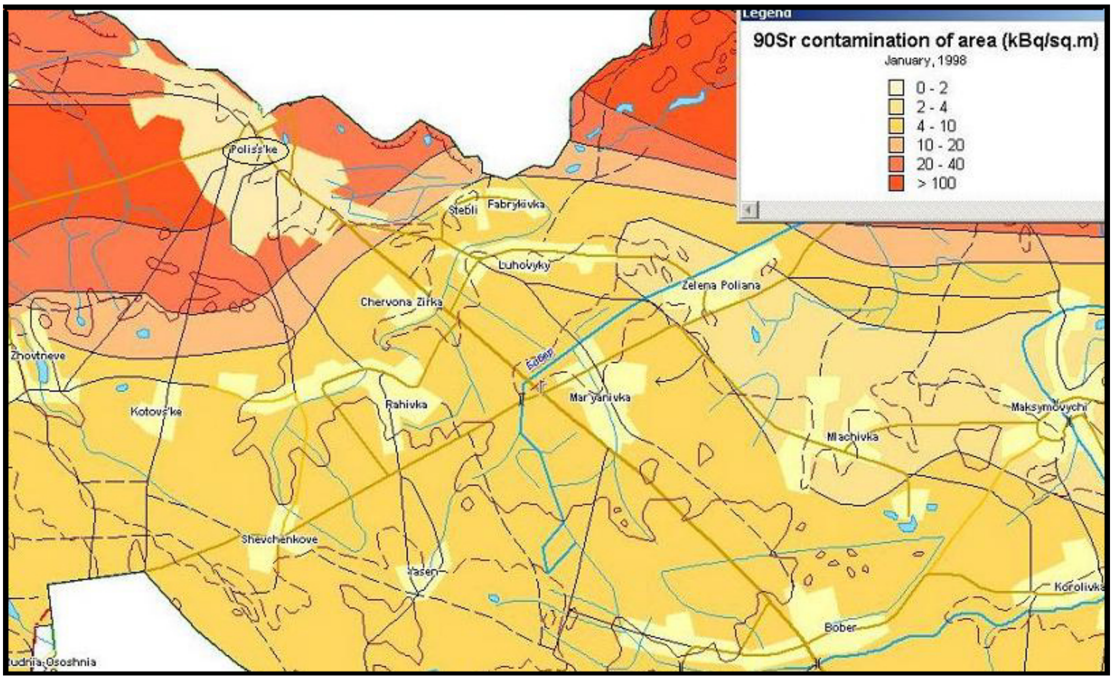
*First rain in Polesskoe after accident at ChNPP.
Total precipitation quantity of May: 8,6 mm

Annex III-2

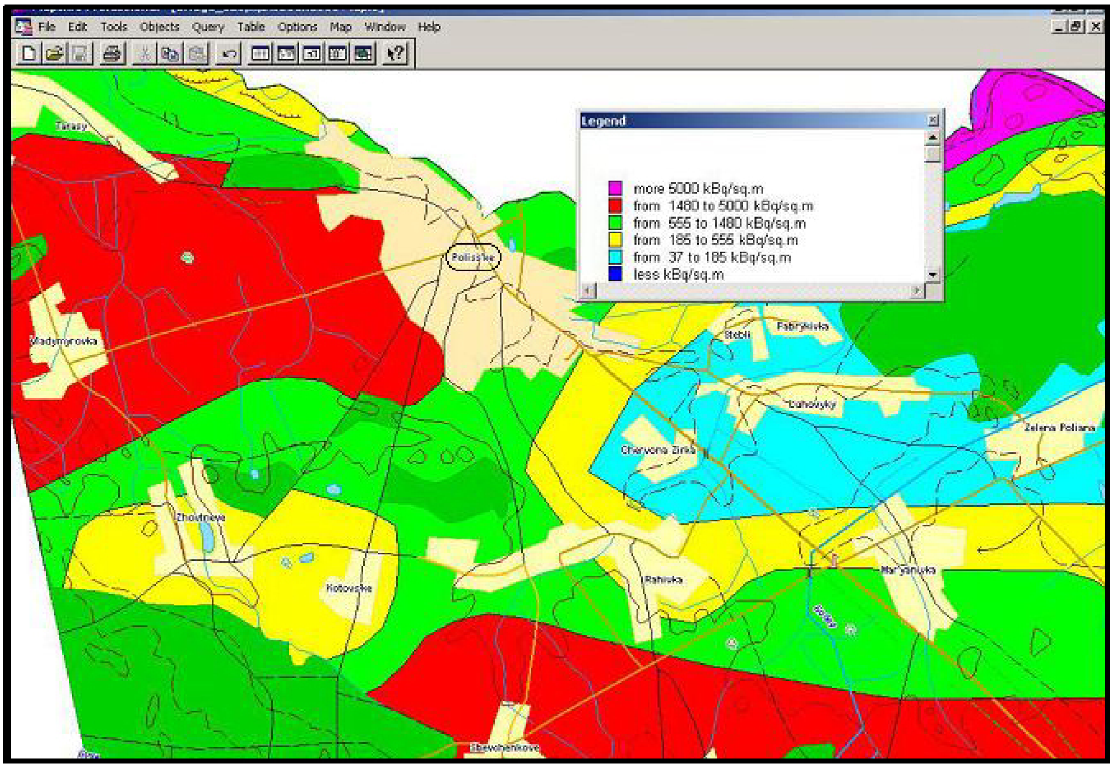
1. Map of ^{137}Cs contamination in the settlement of Polesskoe (MBq/m^2).



2. Map of ^{90}Sr contamination of Polessky raion (kBq/m^2) in January 1998.

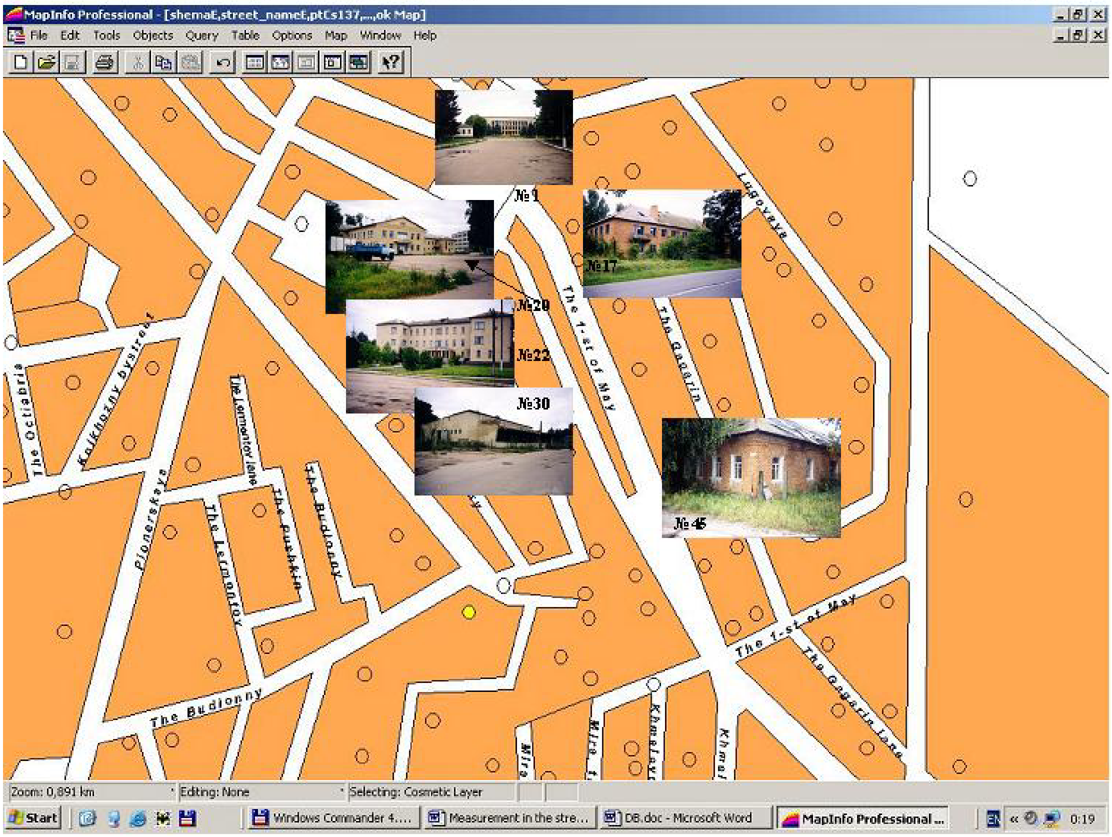


3. Map of ^{137}Cs contamination of Polessky raion (kBq/m^2) in January 1998.



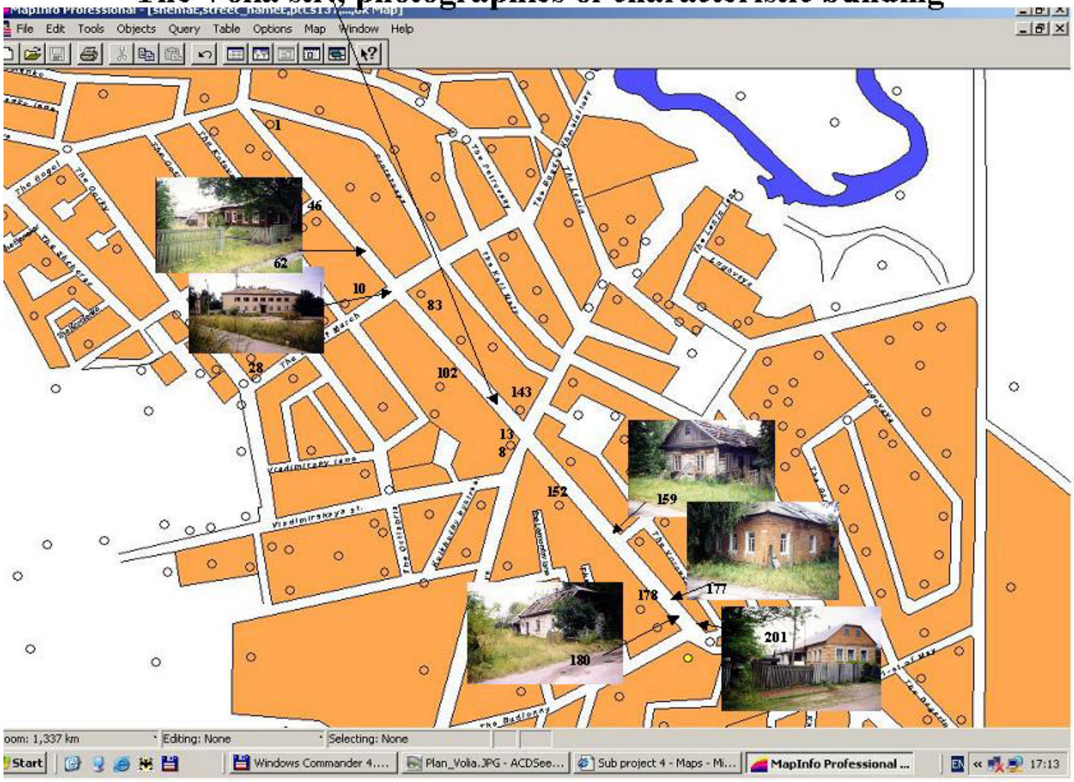
4. A layout of the Polesskoe, 1[st] of May str., photographs of characteristic buildings.

The 1st of May str., photographies of characteristic building



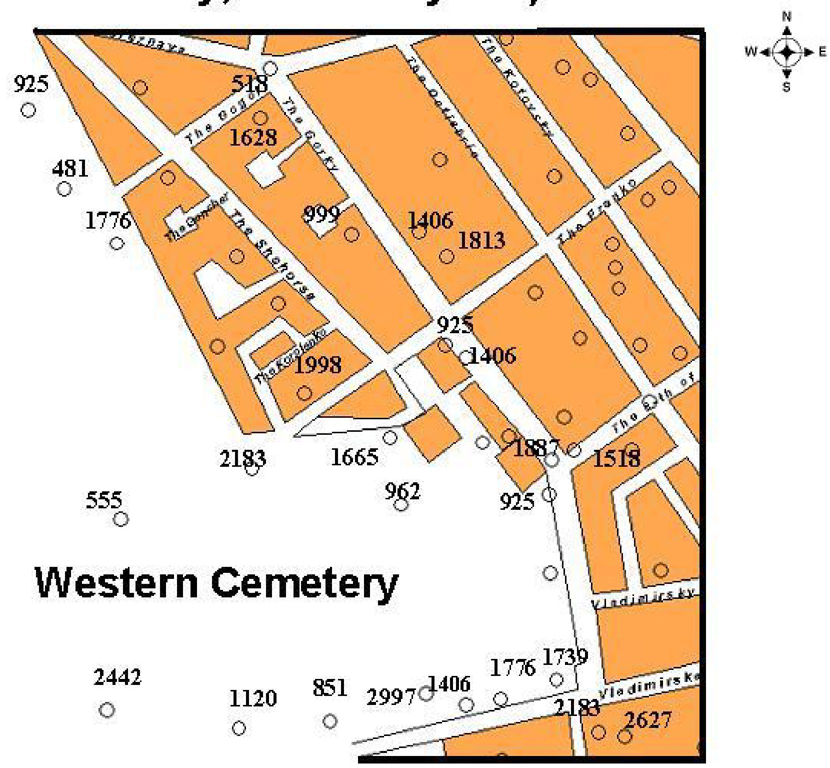
5. A layout of the Polesskoe, Volia str., photographs of characteristic buildings.

The Volia str., photographies of characteristic building



6. A layout of the map of ^{137}Cs (kBq/m^2) contamination of Western cemetery and the Gorky str.

Map of ^{137}Cs ($KBq\ m^{-2}$) contamination Polesskoe, (Western cemetery, The Gorky Str.)



Annex III-3

Results of dose rate measurements at ground level and above ground surface (1 m) in the settlement of Polesskoe in 1986.

Khmelevoy lane

Postal address:	Type of surface street:	1 m:	0 m (ground):	Date of measure:	Units of Measure:
11		0,9	1,0	04.12.1986	µSv/h
16		0,4	0,45	04.12.1986	µSv/h
4		0,75	0,6	04.12.1986	µSv/h
n.s.	grass	-	5,5	08.08.1986	µSv/h

Lugovaya

2	grass	5,0	7,0	19.08.1986	µSv/h
n.s.	grass	5,3	5,5	19.08.1986	µSv/h

Mira, the first line

1	grass	5,3	8,0	19.08.1986	µSv/h
n.s.	ground	5,3	8,0	19.08.1986	µSv/h

Naberezhnaya

98	grass	1,5	2,2	28.10.1986	µSv/h

Peschanny

14		0,5	0,45	05.12.1986	µSv/h
28		1,2	1,6	05.12.1986	µSv/h

Pionerskaya

3	grass	3,5	-	30.10.1986	µSv/h
31	grass	-	2,0	30.10.1986	µSv/h
34	grass	0,35	-	01.07.1996	µSv/h
37	grass	0,35	-	01.07.1996	µSv/h
79	grass	3,5	-	30.10.1986	µSv/h

Polevaya

29		1,2	0,5	05.12.1986	µSv/h
56		0,5	0,2	05.12.1986	µSv/h

Polevoy lane

1		2,0	2,8	05.12.1986	µSv/h

Proletarskaya

16		1,8	1,6	05.12.1986	µSv/h

Proreznaya

19		1,4	1,0	11.12.1986	µSv/h
73		1,4	1,0	11.12.1986	µSv/h
n.s.	grass	6	7,5	19.08.1986	µSv/h

Rechnoy lane

2		0,75	1,0	05.12.1986	µSv/h

Sadovaya

108		0,75	0,5	04.12.1986	µSv/h
21		0,7	0,65	04.12.1986	µSv/h
7		0,9	0,75	04.12.1986	µSv/h
85		0,75	0,3	04.12.1986	µSv/h
29	grass	-	0,35	01.07.1996	µSv/h

Sadovy lane

4	grass	3,5	-	08.08.1986	µSv/h

Sovkhozny the 2-nd lane

n.s.		0,5	0,65	05.12.1986	µSv/h

The 1-st of May

n.s.	grass	4,6	5,5	19.08.1986	µSv/h
n.s.		1,1	2,4	04.12.1986	µSv/h

The 25-th of October Square

n.s.	grass	1,2	1,8	30.10.1986	µSv/h

The Bogdan Khmelnitsky

10	grass	5,0	6	19.08.1986	µSv/h

The Budionny

19	grass	2,5	-	30.10.1986	µSv/h

The Franko lane

n.s.	grass	5,0	5,5	19.08.1986	µSv/h

The Gagarin

2	grass	5,0	5,5	19.08.1986	µSv/h
25	grass	5,0	5,2	19.08.1986	µSv/h
37	grass	3,0	5,5	29.10.1986	µSv/h
38	grass	6,0	5,0	19.08.1986	µSv/h
45		1,0	0,9	11.12.1986	µSv/h
7		2,4	2,8	11.12.1986	µSv/h
n.s.	grass	5,0	5,2	19.08.1986	µSv/h

The Gorky

2	grass	2,0	3,2	28.10.1986	μSv/h
39	grass	2,5	4,0	28.10.1986	μSv/h
64	grass	1,3	-	30.10.1986	μSv/h
n.s.	grass	5,0	-	08.08.1986	μSv/h

The Karl Marx

44	grass	1,8	1,0	11.12.1986	μSv/h
65	grass	6,0	10,0	19.08.1986	μSv/h
84	grass	-	0,35	01.07.1996	μSv/h

The Kotliarevsky

1	grass	2,5	3,0	28.10.1986	μSv/h

The Kotovsky

1	grass	2,5	3,0	28.10.1986	μSv/h
32	grass	6,0	7,0	18.08.1986	μSv/h
38	grass	2,9	3,3	28.10.1986	μSv/h
n.s.	ground	6,0	10,0	19.08.1986	μSv/h
n.s.	grass	6,0	7,5	19.08.1986	μSv/h

The Kotsiubinsky

17		1,6	1,2	05.12.1986	μSv/h
31		1,6	2,8	05.12.1986	μSv/h

The Lenin

6	grass	6,5	-	09.07.1986	μSv/h
8	grass	1,8	-	30.10.1986	μSv/h
n.s.	grass	5,5	-	08.08.1986	μSv/h
n.s.	grass	5,0	-	08.08.1986	μSv/h
n.s.	grass	5,5	7,0	19.08.1986	μSv/h

The Lermontov

8	grass	0,35	-	01.07.1996	μSv/h

The Octiabria

7	grass	4,0	-	30.10.1986	μSv/h
n.s.	grass	4,5	5,0	19.08.1986	μSv/h
n.s.	grass	7,5	9,0	19.08.1986	μSv/h
n.s.	grass	6,0	7,5	19.08.1986	μSv/h

The Octiabria lane

7	grass	4,0	-	30.10.1986	μSv/h

The Petrovsky

37	grass	5,0	5,2	19.08.1986	μSv/h
37	grass	5,5	7,5	19.08.1986	μSv/h
45		0,8	0,55	05.12.1986	μSv/h
n.s.	grass	5	5,5	19.08.1986	μSv/h
n.s.	grass	6,5	8,0	19.08.1986	μSv/h
n.s.	grass	5,5	7,5	19.08.1986	μSv/h

The Shevchenko

16		1,0	1,0	05.12.1986	μSv/h

The Vorovsky

n.s.	grass	2,0	2,5	29.10.1986	μSv/h
n.s.	grass	1,0	1,4	29.10.1986	μSv/h

Vesenniaya

1		0,6	0,75	04.12.1986	μSv/h
n.s.	grass	3,1	-	08.08.1986	μSv/h

Vishniovy lane

4		2,0	2,2	05.12.1986	μSv/h

Vladimirskaya

40	grass	4,0	-	30.10.1986	μSv/h
n.s.	grass	5,5	6,0	19.08.1986	μSv/h
n.s.	grass	-	1,0	13.07.1986	μSv/h
n.s.	grass	-	2,0	13.07.1986	μSv/h
n.s.	grass	-	2,8	13.07.1986	μSv/h
n.s.	grass	-	3,0	13.07.1986	μSv/h
n.s.	grass	5,5	6,5	19.08.1986	μSv/h
n.s.	grass	6,0	7,5	19.08.1986	μSv/h
n.s.	grass	2,0	2,3	19.08.1986	μSv/h
n.s.	grass	2,0	5,5	19.08.1986	μSv/h
n.s.		-	3,0	13.12.1986	μSv/h
n.s.	grass	-	5,0	10.08.1987	μSv/h
n.s.	grass	7,0	9,0	19.08.1986	μSv/h

Volia

42	grass	-	5,0	09.07.1986	μSv/h

Zarechnaya

n.s.	grass	4,5	-	08.08.1986	μSv/h
n.s.	grass	5,0	-	08.08.1986	μSv/h

IV. SLAVUTYCH

History of town
An accident at the Chornobyl NPP caused an evacuation of the whole population from the NPP's residential town Pripyat. Subsequent radioecological surveys showed the impossibility of using this town for further living. When resumption of work at the Chornobyl nuclear units became necessary, a decision was made to look for a location for a new residential town for the NPP's staff. Among a number of possibilities, the most preferable was to build the town on the left bank of the river Dniper, about 35 km northeast of the NPP, near the village Nedanchichy. There were railway connections with the Chornobyl NPP and the regional center of Chernigov. The radioecological situation directly near Nedanchichy was relatively favourable. However, after thorough inspection of the grounds, this site was declined, due to too high a ground water level and too light soils. As a result, it was decided to begin construction of the new town 10 km farther to the east, on a more elevated forest area. The decision was made in October 1986, and in December 1986 the first builders came there.

The town was built very intensively by the efforts of eight former Soviet Union Republics. By the end of 1987 almost all elements of urban infrastructure and most of the first phase of residential buildings had been built up. Officially the NPP's workers, the town's builders, and their families were settled there starting in March 1988. Construction of the basic part of Slavutych was finished by 1990. Further building up of the town was continued only by the efforts of Ukraine. The total area of the town is about 720 ha, including up to 60 ha of internal green areas and up to 200 ha of recreation areas surrounding residential and industrial areas. Currently, the town has 12 residential blocks of 1-, 2-, 5-, and 9-storied buildings, 1 non-residential center, a block containing a medical complex, and an industrial area. In total, there are more than 700 buildings of different kinds. About 2-4 km west of Slavutych there is a second industrial area (app. 100 ha). The town has railway and bus communication with other regions of Ukraine (before the mid-1990s there was river communication with Kiev and Gomel). The way to the Chornobyl NPP takes up to 30 minutes by train and up to 1 hour by bus (currently the travel time is related to the customs procedure at the crossing of the Byelorus border).

Since the town was built on territory contaminated by the Chornobyl accident, it was necessary to carry out complex decontamination works. Basically these works were carried out in 1987-1992. Now the Slavutych area is almost totally decontaminated (down to pre-accident levels), but situated between two relatively high radioactive spots.

For ten years Slavutych remained a mono-industrial town and depended on the success of the nuclear power plant. Nearly 40% of the adult population worked at the NPP. Due to a state decision to decommission the Chornobyl NPP, in December 2000 the last (third) nuclear unit was stopped (the second one was stopped in 1991, the first one in 1996). This was reflected in the demographic situation in the town, causing some emigration and rotation of the population. The activity of citizens reoriented toward creation of new enterprises both in the Chornobyl zone and in the Slavutych area. In 1991 up to 20,000 people lived in Slavutych; by the mid-1990s, up to 26,000, and by 1 June 2003, there were 24,300 citizens, including nearly 8,000 children (up to 16 years old). No more than 25% of the adult population works directly at the ChNPP now.

More detailed descriptions of the town and its history are presented in Annexes IV-1 and IV-2.

Location and landscape (town description)

The town of Slavutych is situated 48 km NE from the Chornobyl NPP (105°), 38 km W of the regional center of Chernigov (distance to Kiev, 200 km by road to the south), and on the left bank of the river Dniper (12 km E of the river) (Figure IV-1).

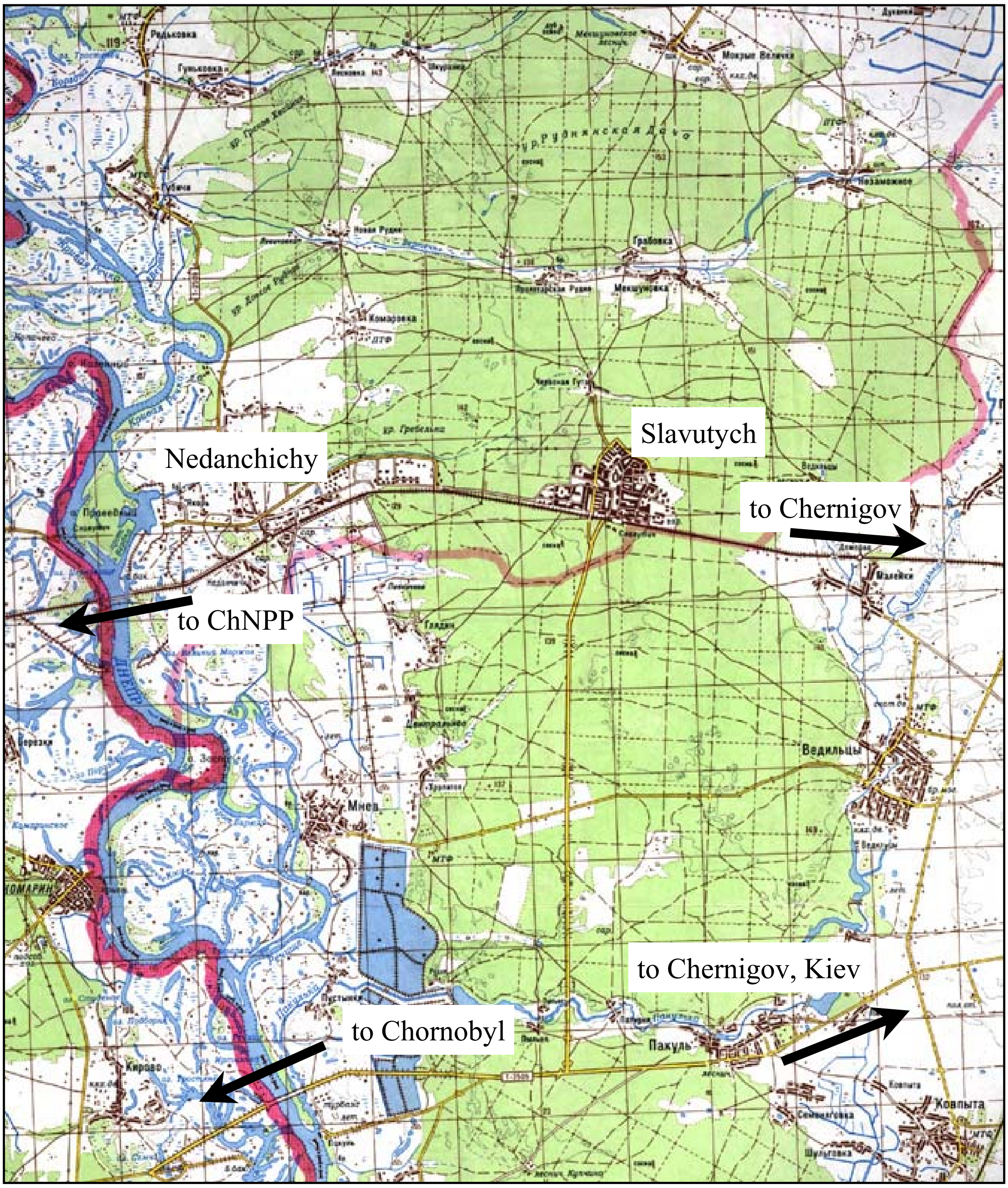


Figure IV-1. – Part of a raster map, showing the location of the town of Slavutych (1:100 000).

There is a second terrace above the Dnieper's floodplain. The town surface topography is mainly flat, with a small slope towards the west (from 146-147 m to 136-137 m), and within most of the region the elevation amounts to 141.4 m. The altitude differential at the terrace is approximately 36 m. The surroundings of the town consist mainly of pine trees or mixed forest (40-90 years old). Meadows of the river floodplain are 5-8 km to the west; there are also meadows and arable lands 5 km to the east. The town has railway and developed road communications with other regions (before the mid-1990s it also had river communications).

Structure of the urban area

The town has an area of about 7.2 km^2 (including the industrial area and the surrounding recreation area; without the recreation area it is 4.25 km^2). Structurally, there are twelve residential blocks ('quarters'), one non-residential town center, a block of medical complex, and an industrial area (Figure IV-2). In the eastern outskirts there is an open area (app. 15 ha), on a place of the 'eastern' radioactive spot that was totally decontaminated in 1990-1993. There is a place for future construction of the next phase of the town. Currently, there is a poor wood (young pine trees, birch, willow) and grass vegetation, and up to 15 unfinished 1- and 2-storied buildings.

Figure IV-2. - Layout of the Slavutych territorial structure.

Almost all first blocks of the town have remains of forest woods, which were there before 1987. However, on most parts of the urban area, all trees were cut and removed because of their relatively high contamination. All original soil cover (5-10 cm upper layer) was removed and replaced by new soil, brought from a relatively 'clean' area (3 km north of Slavutych).

The buildings occupy app. 12.7% of the total area (4.25 km^2); asphalt and concrete coverings, 24.9%; parks (pine and birch trees), not more than 7.8%; private gardens with cultivated soils and planted trees, 11.8%; and lawns and other areas, 42.8% (Figure IV-3; at least half of the last category consists of unfinished building sites). There are several public park areas and a sports stadium. The town has a developed system of industrial and storm sewage, road network, and other communications.

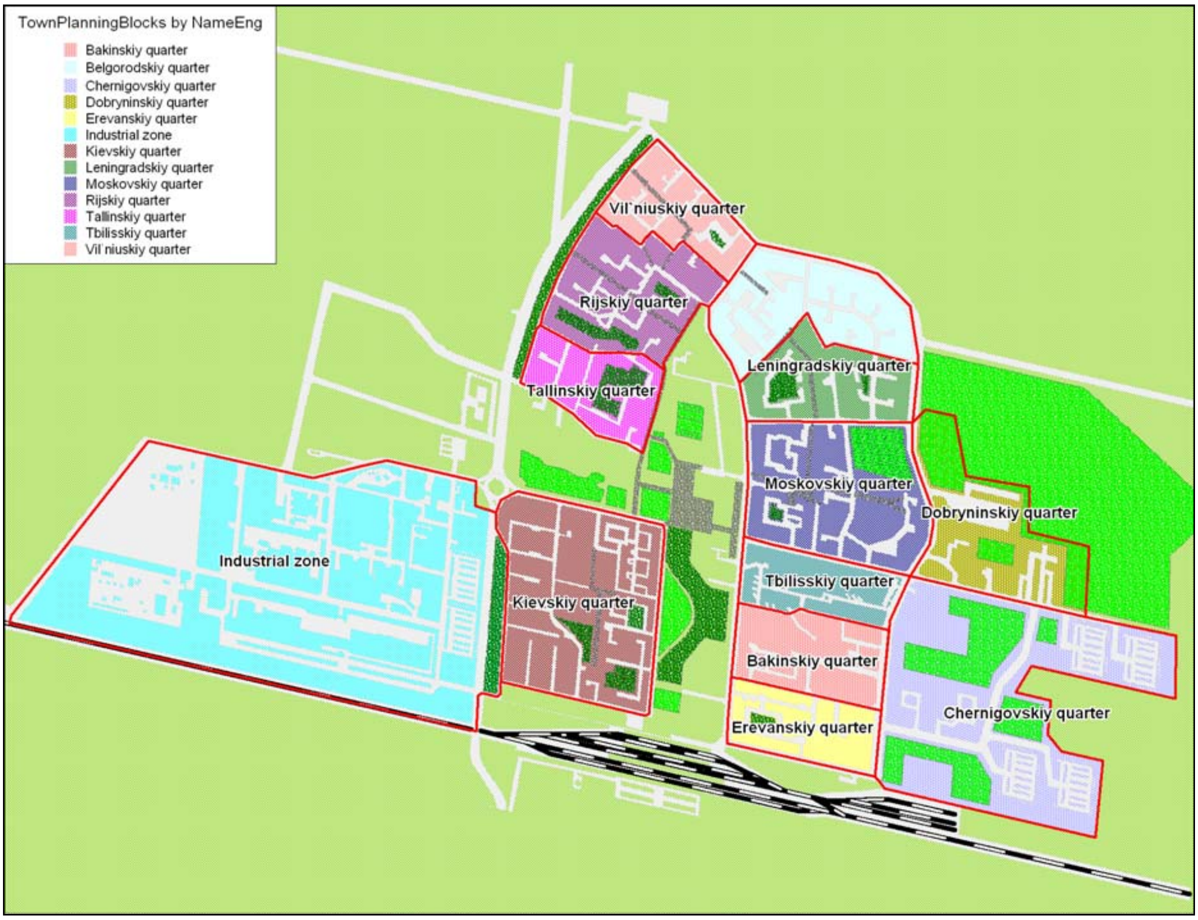


Figure IV-3. - Slavutych territorial structure showing areas of buildings and vegetation.

Type of soil and vegetation

Before construction activities started, the site contained white-mossed and green-mossed pine trees or mixed (birch, oak) forests of artificial origin. Soils are represented by soddy, weakly podzolic powder-sandy ones.

In the course of constructing the town the local landscape and ecological conditions were considerably changed. The fact that trenches were several meters deep resulted in irreversible changes in lithologic and groundwater conditions. Light, sandy soils were reinforced with gravel mounds that were littered by construction waste. In this way, the current site was formed, with different texture and chemical characteristics of soil than before. The following post-construction recultivation activities were added to these changes: filling a peat or meadow sod layer, using organic and mineral fertilizer (mainly on private gardens areas), and artificial irrigation. As a result, a rather complicated pattern of soil-substrate conditions and vegetation cover has emerged.

Deciduous vegetation of the town is represented mainly by trees and bushes of artificial planting (chestnut, lime, maple, poplar, locust, etc.), or remains of original wood-stands (oak, birch). At least half of the wood-stands are pine trees of pre-accident planting (the age varies from 20 to 80 years). There are some rose and other bushes, and many flower-beds and lawns. There are arable plots within private gardens, and also flower-beds and small plots around the trunks of trees. Traditionally fallen foliage and grass are taken away.

Building types

In the town there are both one- and two-storied cottages and multistoried residential buildings (5- or 9-storied). Almost all the town blocks have both multistoried buildings (close to the town center) and cottages (peripheral area). In total, more than 700 buildings are located in the town and out on surrounding area (Figure IV-4); about half of these are apartment buildings.

Almost all multistoried buildings have plane (flat) roofs, waterproof external surfaces, and external balconies. A few multistoried buildings have gable roofs also. The one- and two-storied cottages have mainly gable roofs. Most of the buildings are from large or medium size concrete blocks; some are from bricks and finished with ceramic tiles.

The town has a district heating, water and power supply.

The data base of buildings includes the height of buildings and the number of stories in the buildings, so it is possible to make a 3-dimensional (3D) model of the town, which is useful for modeling the initial redistribution of radionuclides through town compartments. Figure IV-5 compares photographic views and 3D images.

Population and activities

As of 1 June 2003, the town had 24,390 people (including app. 8,000 children) and a population density of app. 5,700 people per km^2. The average age was 30 years. A considerable part of the adult population is busy in operative, service and management works at the Chornobyl NPP. Many people worked at the building sites and with other organizations in the Chornobyl zone. There are 9 kindergartens, 4 schools, 1 high school (branches of two universities), 1 art school, 9 sport complexes, a large medical complex, a research center, theaters, many shops and markets, and buildings for services and facilities (municipal, greenhouses, transport parks, garages, etc.). A lot of people are busy with municipal and transport services, in trade, and in private business.

Contamination

The Slavutych urban area was contaminated as a result of the Chornobyl accident, mainly during 28-29 April 1986, during conditions of rain precipitation. Before May 1987, nobody carried out any detailed survey of local radiation conditions. In 1987-1994, as a result of a series of surveys, a dataset was obtained about radioactive contamination of soil, vegetation and air in the area of the Slavutych construction. An aero-gamma survey of 1995 gave a more detailed description of the pattern of radioactive contamination in the 15-km zone around Slavutych (Figure IV-6). Because the surveys were non-systematic (irregular, incomplete, by different volumes and methods) and independent (by different groups of researchers), they gave different (sometimes, ambiguous and contradictory) estimations of the radiation situation in Slavutych and the surrounding territory.

Figure IV-4. Typical types of apartment buildings and other residential buildings in Slavutych.

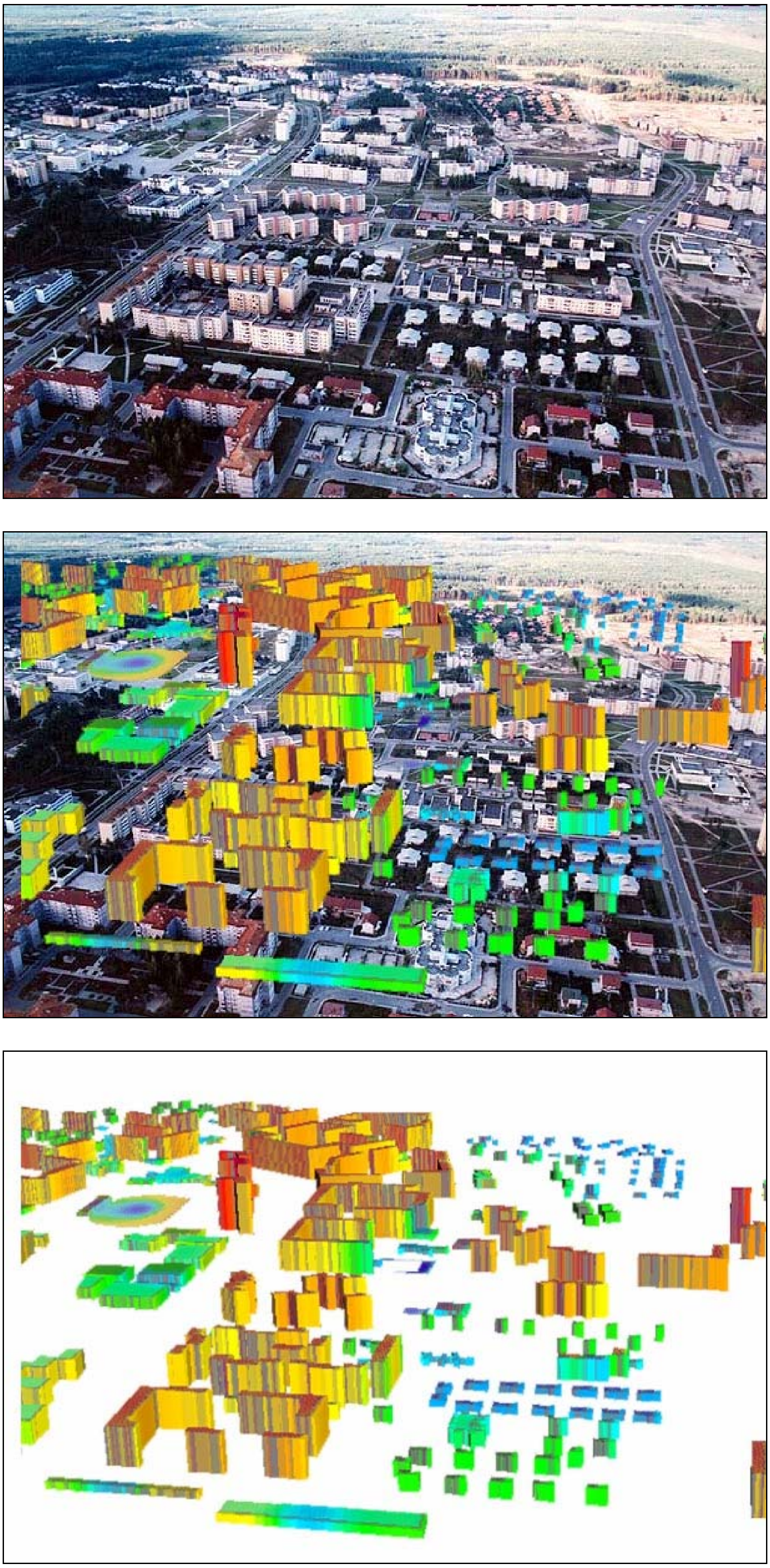


Figure IV-5. – Photographic view and 3D model of the town.

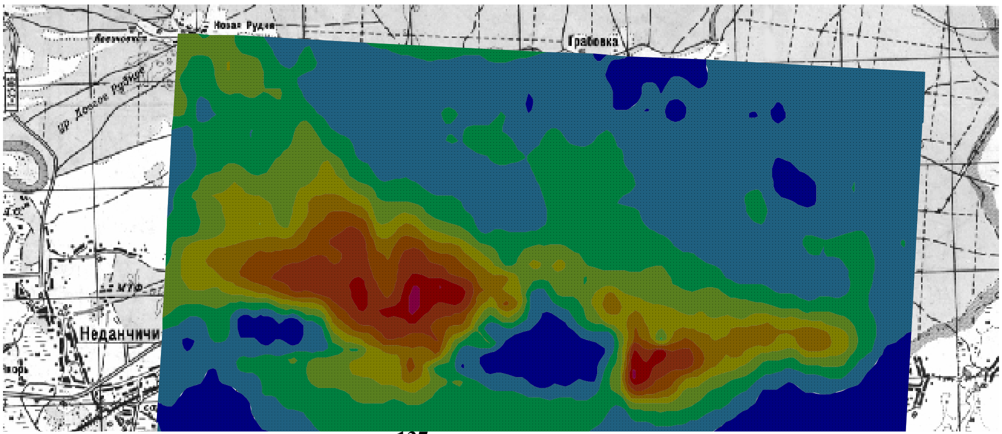


Figure IV-6. Contamination of soil by ^{137}Cs in Slavutych area according to data from an aero-gamma survey in 1995, kBq/m^2.

In the summer of 1987, the average exposure dose rate at the town building area was 0.07 ± 0.015 μSv/h (Table IV-1; before the accident it was 0.008±0.01 μSv/h). The dose rate was somewhat higher along the perimeter of the building area (maximum, 0.17 μSv/h). The average beta-flow rate of the soil was 450±83 count/min cm^2; on forest plots, 610±160. Radiation conditions were defined mainly by contamination of the upper layer of soil and the trees (Table IV-2). Of the total radioactive deposition, 65% was in the forest litter, 20% in the upper 1-2 cm humus layer, and up to 15% in the underlying 0-5 cm sand layer. The average contamination of the building area was defined to 0.074-0.74 MBq/m^2, including 0.026-0.59 MBq/m^2 of ^{137}Cs. The amount of ^{90}Sr deposition varied between 1.9-15 kBq/m^2 limits, ^{239,240}Pu, 19-60 Bq/m^2. On lands adjoining the building area, the average soil contamination was as follows: ^{137}Cs, up to 0.48 MBq/m^2; ^{90}Sr, up to 0.037 MBq/m^2; ^{239,240}Pu, up to 740 Bq/m^2. Two large spots of the radioactive fallout were found close to the building area: ‘western’ and ‘eastern’ (more likely, they were formed as a result of the division of one large spot by the construction activity). A summary of the average gamma dose exposure rates each year is given in Table IV-3.

Table IV-1. Gamma exposure dose rate and β-flow rate at the Slavutych building area in the summer of 1987 (data from pedestrian survey).

Location	Gamma Mean ± SD (n) ×10^{-3} μSv/h	Beta Mean ± SD (n) count/min·cm^2
Perimeter of building area	70±17 (108)	460±83 (76)
Inside building area	53±23 (77)	570±80 (28)
Medical complex (west region)	63±32 (23)	450±240 (11)
‘Baltic’ (north region)	51±13 (19)	600±160 (10)
‘Ukraine’ (south-west region)	59±19 (15)	390±230 (16)
‘Armenia’ (south-east region)	35±11 (11)	450±230 (5)
Settlement ‘Lesnoi’	85±20 (10)	290±190 (18)

Table IV-2. Contamination of soil in the Slavutych town area, 1987.

Location	Percentage, %					Density, MBq/m^2
	^{106}Ru	^{144}Ce	^{134}Cs	^{137}Cs	$^{95}Zr + {}^{95}Nb$	
Near railway	24	28	12	28	8.1	0.43
Near cemetery	24	22	13	36	6.3	0.34
300 m north-west from cemetery	22	29	12	29	7.3	0.40
North outskirt	19	25	13	27	6.6	0.38
Northeast outskirt	17	23	13	34	6.3	0.42
600 m northeast	17	18	18	42	4.7	0.46
Near railway station	16	22	13	37	3.8	0.79
Near medical complex	10	25	7.8	22	2.4	2.6

Table IV-3. Average gamma exposure dose rate at five reference points near the Slavutych area, □Sv/h.

Year	Reference points				
	1	2	3	4	5
1988	0.024	0.038	0.061	0.047	0.093
1989	0.016	0.032	0.048	0.041	0.083
1990	0.014	0.030	0.045	0.033	0.069
1991	0.013	0.025	0.029	0.025	0.056
1992	0.013	0.021	0.027	0.022	0.044
1993	0.012	0.020	0.025	0.021	0.038
1994	0.011	0.017	0.022	0.018	0.032
1995	0.010	0.016	0.021	0.017	0.030
1996	0.0095	0.014	0.019	0.016	0.027

Decontamination of the Slavutych urban area

Because large-scale construction of the town had begun before the detailed radiation survey was performed, practially all of the new buildings built in 1987-1988 were erected without proper decontamination of the areas (Kievsky, Tallinsky, Rizhsky, Vilnusky, Belgorodsky, Leningradsky, Moskovsky, Tbilisky, Bakinsky and Yerevansky quarters, city center, medical complex, industrial area). In the summer of 1987 it was found that relatively high radioactive contamination existed in most of the Slavutych area. By the beginning of decontamination efforts, the Slavutych area had two types of lands:

- Plots with completely destroyed structure of ground surface (due to construction activity) with dose rate 0.01-0.04 □Sv/h and $^{134}Cs+{}^{137}Cs$ contamination 7.4-56 kBq/m^2.
- Plots with untreated native forest cover with dose rate 0.035-0.17 □Sv/h and $^{134}Cs+{}^{137}Cs$ contamination 100-2600 kBq/m^2.

Since 1988, based on a control level of 0.03 □Sv/h at 1 m height (Table IV-4), it was decided to carry out a complex of decontamination measures:

- Removal of the most contaminated plots (including soil and wood vegetation), up to 0-30 cm depth;
- Removal of bark on the rest of the trees up to 2 m height of trunk, removing of forest litter;
- Covering of soil with peat and sod from 'clean' areas, up to 0-10 cm layer;

- Planting of perennial grass and shrubs; and
- Application of dust-suppression technology on roads, foot-paths, and squares and around buildings.
- In 1988-1991 the following activities were performed:
- Removal of forest areas from the ‘eastern’ radioactive spot, 29,000 m^3 (40 ha);
- Removal of lower branches from trees on the ‘western’ radioactive spot (2900 trees);
- Thorough decontamination of areas around kindergartens and schools;
- Asphalting or concreting of roads, foot-paths and squares; and
- Covering of fertile soil layer and grass vegetation.
- By 1990 the gamma dose rate did not exceed the control level of 0.03 □Sv/h on most parts of the Slavutych area. There remained only a few more contaminated plots, such as:
- Forest area remains where construction work has not been carried out yet (city center, Moskovsky quarter, and others);
- Areas where construction works were carried out without prior decontamination;
- Areas where the technique of decontamination has not given positive results (native vegetation areas at kindergartens in Leningradsky, Rizhsky and Vilnusky quarters).

Further, taking into account the latter circumstance, decontamination of unbuilt areas included total removal of the 0-10 cm upper layer of soil and native vegetation. In several locations decontamination efforts were performed repeatedly until acceptable radiation conditions were reached. Construction of parts of the Belgorodsky, Moskovsky, Tbilisky, Bakinsky, Yerevansky quarters, and of new quarters (Chernihovsky and Dobryninsky), was carried out with prior total decontamination of the lands. Since 1992, the decontamination works have had a limited local character, and they were finished by 1994. Adjoining forest recreation areas were mostly not decontaminated, except for the parts closest to the city and the hottest plots (removal of forest litter, bark and lower branches of pine trees). Average values of radiation parameters with and without decontamination measures are shown by year in Table IV-5. Results of β,γ-surveys in 1992 and 1999 are provided in Tables IV-6 and IV-7.

Table IV-4. Description of some plots of the city where radioactive contamination exceeded an acceptable level (0.03 □Sv/h) in 1989.

Location (city quarter)		Gamma, ×1̃. □Sv/h	Beta, counts /min cm^2
Center	Square between shop ‘Minsk’ and cinema-concert hall	34-44	25-30
Bakinsky	Eastern edge	31-40	15-25
Tbilissky	Near building No. 6	24-32	18-28
Moskowsky	Forest remains at eastern edge	42-95	35-55
Belgorodsky	Pine trees plot	42-52	24-36
Belgorodsky	Near building No. 10	30-50	26-40
Rizhsky	Tree line along circumferential road	20-39	10-18
Rizhsky	Birch trees stands near cottages	61-69	110-130
Rizhsky	Yard of buildings No. 2-7	20-42	10-15

Table IV-5. Average values of radiation parameters in Slavutych with and without decontamination measures.

	Areas with decontamination of soil and vegetation			Areas without decontamination
Year	Beta, counts/min cm^2	Soil contamination, kBq/m^2	Dose rate, µSv/h	Dose rate, µSv/h
1986	600-1200	590	0.140	0.140
1987	400-800	520	0.070	0.070
1988	20-200	220	0.035	0.048
1989	8-160	140	0.022	0.038
1990	5-130	67	0.018	0.034
1991	3-110	32	0.016	0.030
1992	2-90	30	0.014	0.029
1993	2-39	29	0.013	0.028
1994	2-32	28	0.012	0.026
1995	2-15	28	0.012	0.026

Table IV-6. Results of pedestrian β,γ-survey in 1992.

Location (city quarter)	Gamma, $\times 10^{-3}$ µSv/h		Beta, counts/min cm^2		N
	Mean±SD	Min-Max	Mean±SD	Min-Max	
Center	12±2.2	9-18	12±6.5	5-19	40
Talinsky	13±1.2	11-15	8.1±2.1	6-10	95
Rizhsky	12±1.9	10-10	12±2.3	6-18	57
Vilnussky	12±1.0	11-14	8.5±2.5	6-14	102
Kievsky	14±2.3	9-20	11±3.9	3-24	131
Tbilisky	10±1.5	8-15	8±2.8	4-18	40
Yerevansky	13±1.7	10-18	7±2.2	3-13	64
Bakinsky	13±1.8	9-17	8±2.9	3-14	43
Chernihovsky	15±2.8	9-20	5±2.0	2-10	144
Dobryninsky	15±2.7	9-21	6±2.0	3-11	74
Moskovsky	14±3.1	8-26	5±1.8	2-12	181
Leningradsky	13±3.0	8-26	12±5.2	5-33	53
Belgorodsky	15±2.7	8-24	7±9	2-90	87
Industrial area	19±8.3	10-41	10±9	3-37	40
Average	14±2.1	8-41	9±2.5	2-90	1151

Table IV-7. Results of pedestrian β,γ-survey in 1999.

	Gamma, $\times 10^{-3}$ μSv/h			Beta, counts/min cm^2		
Location (city quarter)	Mean±SD	Min-Max	N	Mean±SD	Min-Max	N
Center	14.0±3.0	7-27	1039	6.00±2.00	2-15	1031
Talinsky	14.5±2.3	10-21	18	6.82±2.49	4-14	23
Rizhsky	17.7±2.0	10-23	379	7.35±2.08	4-14	379
Vilnussky	20.4±2.3	12-26	376	7.63±2.14	4-14	376
Kievsky	14.7±1.7	10-18	440	8.26±2.37	4-16	434
Tbilisky	16.7±1.0	15-19	255	6.64±1.72	3-10	266
Yerevansky	16.6±1.5	12-21	250	6.82±1.98	3-12	250
Bakinsky	17.8±1.8	13-24	206	6.90±1.88	4-12	174
Chernihovsky	14.0±2.4	9-18	47	6.00±1.61	4-10	41
Dobryninsky	13.0±3.0	8-19	54	7.00±2.00	4-12	54
Moskovsky	16.4±1.5	12-24	677	6.65±1.97	3-15	677
Leningradsky	15.5±1.6	12-18	66	6.60±1.79	3-10	70
Belgorodsky	15.2±2.5	11-24	59	6.00±2.00	3-10	49
Average	16.1±2.8	7-27	4029	6.76±2.00	2-16	3824

ANNEX IV-1

Description of the town of Slavutych

1. Numbers of buildings in different districts of Slavutych

Planning Blocks	Areas Sq. km
Tallinskiy qr.	0.115464
Rijskiy qr.	0.101546
Vil`niuskiy qr.	0.127019
Belgorodskiy qr.	0.164536
Leningradskiy qr.	0.109
Moskovskiy qr.	0.222763
Dobryninskiy qr.	0.178818
Chernigovskiy qr.	0.260665
Erevanskiy qr.	0.093684
Bakinskiy qr.	0.111525
Tbilisskiy qr.	0.089649
Kievskiy qr.	0.30568
Industrial zone	1.423737
Medical complex	0.167529
Non-residential center	0.414022
Building site	0.363889

1.1 Moskovskiy qr.

Number of buildings	Number of stories (floors) in buildings
7	1
5	2
11	5
1	9
2	0

1.2 Leningradskiy qr.

Number of buildings	Number of stories (floors) in buildings
5	5
13	1
9	2

1.3 Belgorodskiy qr.

Number of buildings	Number of stories (floors) in buildings
31	1
7	2
6	5
1	6
1	0

1.4 Industrial zone

Number of buildings	Number of stories (floors) in buildings
46	2
597	1
6	3
3	4
4	0

1.5 Chernigovskiy qr

Number of buildings	Number of stories (floors) in buildings
3	1
1	4
4	9
3	8
14	2
4	5

1.6 Building site

Number of buildings	Number of stories (floors) in buildings
15	2

1.7 Tbilisskiy qr

Number of buildings	Number of stories (floors) in buildings
5	5
7	2
1	0
1	1

1.8 Bakinskiy qr.

Number of buildings	Number of stories (floors) in buildings
10	2
7	5
1	0
33	1
2	3

1.9 Erevanskiy qr.

Number of buildings	Number of stories (floors) in buildings
4	5
20	2

1.10 Kievskiy qr

Number of buildings	Number of stories (floors) in buildings
3	6
8	5
1	3
104	2
2	1
2	0

1.11 Non-residential center

Number of buildings	Number of stories (floors) in buildings
3	9
1	5
2	4
3	3
14	2
11	1
1	0

1.12 Tallinskiy qr.

Number of buildings	Number of stories (floors) in buildings
7	5
3	3
1	2
51	1

1.13 Rijskiy qr.

Number of buildings	Number of stories (floors) in buildings
8	5
39	2
3	1

1.14 Vil`niuskiy qr.

Number of buildings	Number of stories (floors) in buildings
7	1
8	5
34	2

2. Relations of different surfaces

	Name	Material	Areas
			sq. km
1	Alley	Concrete plate	0.061631
2	Roads	Asphalt	1.34129
3	Lawn	Grass	0.582834
4	Trees and Parks	Trees and Bushes and Grass	4.03566

3. Floors (number of floors in buildings)

Ground floor is first floor.

Number of buildings	Number of stories (floors) in buildings
13	no data
758	1
336	2
18	3
7	4
81	5
4	6
3	8
12	9

4. Walls

Number of buildings	Number of stories (floors) in buildings	Wall material
12	9	concrete
3	8	concrete
1	6	concrete+brick
3	6	concrete
74	5	concrete
2	5	concrete+brick
1	5	Brick
4	5	concrete+red tile
4	4	brick+white tile
1	4	Brick
2	4	Concrete
1	3	brick+facing tile
16	3	Concrete
1	3	brick+white tile
6	2	brick+facing tile
230	2	brick
59	2	concrete
4	2	metal
20	2	concrete+red tile
17	2	brick+white tile
13	1	metal
607	1	concrete
2	1	brick+facing tile
5	1	brick+white tile
2	1	metal+brick
50	1	wood
79	1	brick

5. Roofs

1. Flat
2. Sharp roof

Number of buildings	Roof type	Floors (number of stories)
12	01	9
3	01	8
4	01	6
75	01	5
6	02	5
7	01	4
15	01	3
3	02	3
93	01	2
243	02	2
127	02	1
630	01	1
1	No	1
1	?	0
1	01	0
11	-	0

V. References

Bakin R. I., Tkachenko A. V., Sukhoruchkin A. K. (1989): Estimation of efficiency of dust-suppression countermeasures in 30-km zone of ChNPP. Reports of the First All-Union Scientific and Technical Meeting on Results of Chornobyl NPP Accident Consequences Elimination Activities 'Chornobyl-88' (ed. by E.I. Ignatenko). Chornobyl. 6, 233-238.

Baryakhtar V.G., M.D. Bondarkov, S. P. Gaschak, Yu. A. Ivanov, N. P. Arkhipov. Radioecology of Urban Landscape by the Example of Pripyat Town. Environmental Sciences and Pollution Research. Special Issue # 1 (2003), 63—72.

Demin S.N., Mamin A.I., Sukhoruchkin A.K., Ivanov U.P., Bokin R.I. (1992): Local concentrations of radionuclides in the air during anthropogenic activities in the ChNPP area. Reports of the Third All-Union Scientific and Technical Meeting on Results of Chornobyl NPP Accident Consequences Elimination Activities 'Chornobyl-92' (ed. by E.I. Ignatenko). Chornobyl. 1 (2), 318-325

Derevets V.V., S.I. Kireev, S.M. Obrizan, B.O. Godun, V.G. Halyava, P.G. Kupchenko, B.O. Gorskii, O.B. Nazarov, D.I. Gudkov (2001) Radiation state of the Exclusion Zone. 15 years after the accident // Bulletin of ecological state of the Exclusion Zone and Obligatory Evacuation Zone, № 17, April 2001. – PP. 5-19 (In Ukrainian)

Gavriluk V. I., Ageev V. A., Lashko T. N., Muzalev P. N., Odintsov A. A., Sadovnikov L. V., Satsuk V. A., Sherbachenko A. M. (1992): Some aspects of data obtaining on settlement Polesskoe contamination by alfa- and beta- radiators. Reports of the Third All-Union Scientific and Technical Meeting on Results of Chornobyl NPP Accident Consequences Elimination 'Chornobyl-92' (ed. by E.I. Ignatenko). Chernobyl. Vol. 1, Part (2), 304-313.

Gavriluk V. I., Ermakov A. I., Zhidik A. G., Kazakov S. V., Lashko T. N., Muzalev P. N., Sadovnikov L. V., Kharlanov V. B., Shustov A. V., A. M. Sherbachenko (1990): Investigation of contamination density distribution at settlement ‘Polesskoe’ by long-living radionuclides. Reports of the Second All-Union Scientific and Technical Meeting on Results of Chornobyl NPP Accident Consequences Elimination 'Chornobyl-90' (ed. by E.I. Ignatenko). Chernobyl. Vol. 1, Part (2), 149-160.

Karataev B.A., Kondrashov A.A., Mironov E.V., Pavlov A.B., Fenogenov V.A. (1989): Test decontamination of inhabited locality units within the ChNPP 30-km zone. Reports of the First All-Union Scientific and Technical Meeting on Results of Chornobyl NPP Accident Consequences Elimination Activities 'Chornobyl-88' (ed. by E.I. Ignatenko). Chornobyl. 7 (2), 200-207

Karataev B.A., Mironov E.V., Chernichenko A.A., Shuiskii D.B. (1989): Decontamination of buildings and territory of Pripyat, 1986. Reports of the First All-Union Scientific and Technical Meeting on Results of Chornobyl NPP Accident Consequences Elimination Activities 'Chornobyl-88' (ed. by E.I. Ignatenko). Chornobyl. 7 (2), 90-97

Kashparov V. O. (2001): Forming and dynamic of radioactive contamination of environment during an accident on the Chornobyl NPP and in post-accidental period. In collection of scientific articles: Chornobyl. Exclusion zone. Kyev: Naukova Dumka, P. 11—46.

Mesyats S. P., Melnikov N. N., Pshenichnyh V. P., Starodumov V. M., Sukhoruchkin A. K. (1989): Fixation methods of decontaminated areas to decrease radioactive dust-transfer in5 km zone of ChNPP. Reports of the First All-Union Scientific and Technical Meeting on Results of Chornobyl NPP Accident Consequences Elimination Activities 'Chornobyl-88' (ed. by E.I. Ignatenko). Chornobyl. 6, 207-225.

Nad’yarnyh G. V., Shilin S. A., Komarov V. I., Andreev Y. B., Samoilenko Y. N. (1989): Arrangement and efficiency of works on land decontamination in the ChNPP zone. Reports of the First All-Union Scientific and Technical Meeting on Results of Chornobyl

NPP Accident Consequences Elimination Activities 'Chornobyl-88' (ed. by E.I. Ignatenko). Chornobyl. Vol. 7, Part (1), 189-204.
Nosovsky A. V., Oskolkov B. Ya., Ivanov E. A., Udovichenko V. P. (2001): Slavutych. Questions of radiation ecology. Kiev: 'Vyscha Schkola'. 264 P.
Patrilyak K.I., Blagoev V.V., Kuhar V.P., Seliverstov A.E., Andreev U.B., Samoilenko U.N., Boiko V.V., Komarov V.I., Dubashinskii M.I., Ivanov A.B., Belokur V.P. (1989): Experience of dust suppression and consolidation of dust-forming territories within the Exclusion Zone and beyond its borders. Reports of the First All-Union Scientific and Technical Meeting on Results of Chornobyl NPP Accident Consequences Elimination Activities 'Chornobyl-88' (ed. by E.I. Ignatenko). Chornobyl. 6, 192-206
Prokhorenko O. D., Petrov S. V., Tikhomirov D. D., Kochetkov O. A., Glagolev A. I., Tsvetkov V. I. (1989): Forming of radiation situation at massive contamination of territory by radioactive substances (On an example of town Pripyat). Reports of the First All-Union Scientific and Technical Meeting on Results of Chornobyl NPP Accident Consequences Elimination Activities 'Chornobyl-88' (ed. by E.I. Ignatenko). Chornobyl. 1, 34-39
Repin V. S. (1995): Radiological-hygienic importance of radiation sources and doses for population of 30-km zone after the accident on ChNPP. Problem of reconstruction, assessment of risks // A doctoral dissertation. Institute of epidemiology and prophylaxis of radiation injury, National Academy of Medicine
Shilin S. A., Krapchatov V. P., Nad'yarnyh G. V., Komarov V. I., Andreev Y. B., Samoilenko Y. N. (1989): Arrangement and efficiency of dust-suppression works in a special zone of ChNPP. Reports of the First All-Union Scientific and Technical Meeting on Results of Chornobyl NPP Accident Consequences Elimination Activities 'Chornobyl-88' (ed. by E.I. Ignatenko). Chornobyl. 6, 245-251.
Tyutyunnik Ju.G., Bednaja S.M. (1998): Alteration of vegetation cover in urban landscapes of the Chernobyl NPP Exclusion zone. Ukraine National Academy of Sciences. Diversified scientific and technical center 'Shelter'. Preprint 98-5. Chornobyl, 40 P.
Zykov A. A., Orlov M. I., Shamov V. P. (1989): Prediction of dose burden of the staff, living in the town of Pripyat. Reports of the First All-Union scientific & technical meeting on results of the accident consequences elimination at the Chernobyl NPP. Chernobyl-88. Vol. 3, Part. 1, P. 139-145

Reports about Pripyat:
Chornobyl catastrophe (1997): Ed. by V.G. Baryakhtar. Kiev, 576 P.
Chernobyl: Radioactive contamination of natural environments (1990): Ed. by Yu.A. Izrael. Leningrad: Gidrometeoizdat. 296 P.
Report on scientific and research work «Assessment of consequences of using different territory decontamination techniques». № 13/162n-99, State Specialized Scientific and Industrial Enterprise «Chornobyl Radioecology Center». 2001 (In Ukrainian)
Radiation monitoring of the Exclusion Zone (Review prepared by State Enterprise «RADEK») (1997) // Bulletin of the Exclusion Zone ecological state. February 1997, № 4(9) - PP. 8-28 (In Russian)

Reports about Slavutych:
Assessment of radiation situation near town of Slavutych / Report of External dosimetry department. Industrial association 'COMBINAT'. Pripyat, 1988. P. 1—41.
Complex investigation of radioactive contamination of Slavutych and it's 10-km zone / Report of Research Institute for Nuclear Power Plant (Russia). Moscow, 1990. P.1—35.

Complex investigation of radioactive contamination of Slavutych and it’s 10-km zone / Report of Research Institute for Nuclear Power Plant (Russia). Moscow, 1991. P.1—34.
State of radiation situation in the town of Slavutych in 1991 / Report of Laboratory of External Dosimetry of Chornobyl NPP. Slavutych, 1991. P. 1—23.
The protocol of results of pedestrian gamma- and beta- survey on Slavutych area in term of 14—20 May 1992 / By Complex Expedition of Research Institute for Nuclear Power Plant (Russia) and Laboratory of External Dosimetry of Chornobyl NPP. Slavutych, 1992. P. 1—6.
The protocol of measurement results of radionuclide content in soil on Slavutych area / By Complex Expedition of Research Institute for Nuclear Power Plant (Russia) and Laboratory of External Dosimetry of Chornobyl NPP. Slavutych, 1992. P. 1—20.
The protocol of inspection results of soil plots with increased cesium content on Slavutych area in 1992 / By Complex Expedition of Research Institute for Nuclear Power Plant (Russia) and Laboratory of External Dosimetry of Chornobyl NPP. Slavutych, 1992. P. 1—23.
State of radiation situation in the town of Slavutych in 1992 / Report of Laboratory of External Dosimetry of Chornobyl NPP. Slavutych, 1992. P. 1—50.
The protocol of results of pedestrian gamma-, beta- survey and investigation of radionuclides distribution in soil on territory of forest biogeocenosis around Slavutych in 1992 / Enterprises ‘ECORAD’. Slavutych, 1992. P. 1—15.
The protocol of measurements results of external exposure integral dose on territory of forest biogeocenosis around Slavutych in 1992 / Enterprises ‘ECORAD’. Slavutych, 1992. P. 1—9.
The protocol of investigation results of radionuclide distribution in compartments of forest biogeocenosis around Slavutych (July—September 1992) / Enterprises ‘ECORAD’. Slavutych, 1992. P. 1—15.
Radiation situation on territory of second stage of Slavutych building up. Initial data for decontamination grounds / Report by Research Institute for Nuclear Power Plant (Russia). Slavutych, 1993. P. 1—18.
The protocol of results of pedestrian gamma-, beta- survey and investigation of radionuclides distribution in soil on territory of forest biogeocenosis around Slavutych in 1993 / Research Institute for Nuclear Power Plant (Russia). Slavutych, 1993. P. 1—19.
Analysis of radiation situation in Slavutych area (1st half year 1993) / By Complex Expedition of Research Institute for Nuclear Power Plant (Russia) and Laboratory of External Dosimetry of Chornobyl NPP. Moscow—Slavutych, 1993. P. 1—74.
Results of complex investigation of radioactive contamination of Slavutych town area in 1989—1994 period / Report by Research Institute for Nuclear Power Plant (Russia) and Chornobyl NPP (Agreement 386/93 from 31.08.93). Moscow, 1994. P. 1—70.

Appendix A

Additional Background Material

1.2. Top-priority Post-accident Technical Measures
1.2.1. Evaluation of the Fuel State after the Accident

More than 30 fire sites appeared after the explosions in the reactor happened and high-temperature fragments of the reactor's core were shot up and fell onto the roofs, de-aeration stack and turbine hall. Oil-pipe damages, short circuits in the electric cables and intensive thermal radiation caused additional fire sites in the turbine and reactor halls, as well as in the adjacent, partly destroyed premises.

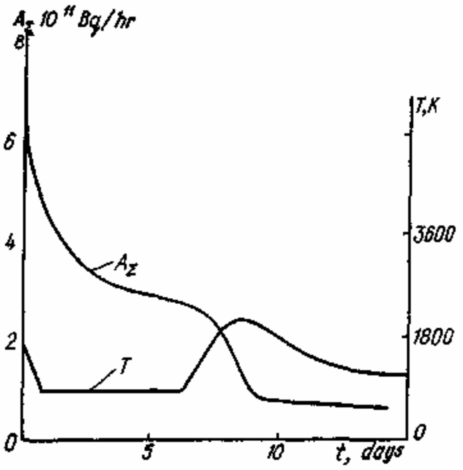


Fig.I.1.2. Fuel activity and temperature time-dependent change

The accident resulted in destruction of the reactor core and its cooling system. In these conditions, the state of the fuel in the reactor pit was evaluated in the following way:

- by residual heat emitted due to fission product decay;
- by heat emitted due to various chemical processes (hydrogen burning, graphite and zirconium oxidation, etc.);
- by heat removal from the reactor pit during its cooling with atmospheric air flow.

Studies aimed at dynamics of the fission product (FP) leakage during the first days after the accident, showed the fuel temperature changes in the course of time to be out of monotony. It suggests several stages in the fuel temperature state. Evaluations have shown that after the explosion the effective temperature of the fuel contained in the reactor hall premises, reached 1600-1800°K. During several tens of minutes that followed the fuel temperature decreased due to heat transfer to the graphite stack and reactor structures, which caused lowering volatile FP leakage from the fuel.

At this time, the value of FP release from the reactor pit was determined mainly by the graphite burning processes, as well as migration processes of finely dispersed fuel and FP encased in graphite by the explosion. Later on, the residual heat made the fuel temperature rise. This resulted in volatile radionuclide (inert gases, iodine, tellurium, caesium) leakage increase. Later elevation of the fuel temperature demonstrated a markedly less volatile radionuclide leakage. This process went on till May 4-5, when the temperature of the residual fuel in the unit was first stabilized and then started falling.

The data received from calculation and evaluation of the fuel state are shown in the Fig.I.1.2. The results given here characterise both the residual fuel radionuclide content and fuel temperature alterations, taking into account FP leakage and its dependence on the time that elapsed after the accident.

Calculations have shown that the maximum fuel temperature did not reach its melting point, and FP appeared on the fuel surface in portions, which could cause only local overheating on the fuel-medium boundary. FP emitted by the fuel, occured on the structural and other kinds of materials that surrounded the reactor. Krypton and xenon radionuclides almost completely dispersed beyond the limits of the reactor unit, volatile FP (iodine, caesium) only partly left the reactor, while almost all other radionuclides remained within the power unit.

1.2.2. Limitation of Radionuclide Effluent from the Reactor Core

Potential risk of a part of the melted fuel to be concentrated and thus to create conditions for the critical mass accumulation and beginning of spontaneous chain reaction, required to take measures in order to prevent this danger.

Besides, the destroyed reactor represented a powerful source of radioactivity emission into the environment. Therefore, it was necessary either to localize the accident by means of heat removing and filtering materials dropped down the reactor pit or let the burning process in the reactor pit cease in a natural way. The first way was chosen.

Since April, 27 military helicopters were used to drop sand, clay, dolomite, leads, boron compounds onto the damaged reactor. Five thousands tons of the materials were dropped there by May 10, as a result, the reactor hall was covered with a layer of loose mass intensively absorbing airborne particles. The reactivity release declined by the 6-th of May to several hundred, and then to tens of Ci/day by the end of May and was out of playing an important part.

At the same time, to lower the residual fuel temperature and decrease oxygen concentration, nitrogen was pumped under pressure into the space under the reactor pit. By the 6-th of May the temperature in the reactor pit stopped rising and started moving down due to the stable convection air flow through the reactor core. By the end of May the situation around the emergency reactor was considerably stabilized.

1.2.3. Stages of Radionuclide Release into the Environment

Radionuclide release beyond the Chornobyl NPP emergency unit premises was a long process that included several stages. First, there was a release of the dispersed fuel from the destroyed reactor. At this stage, the released radionuclide composition approximately corresponded to that in the irradiated fuel, but enriched with volatile nuclide compounds of iodine, tellurium, caesium, and noble gas. The release reached 12 MCi on the first day of the accident.

During the second stage that lasted from April 26 till May 2, the release rate gradually decreased, due to the measures aimed at filtering released substances and ceasing the graphite burning. The hot air streams coming from the reactor, carried finely dispersed fuel and graphite burning products (On May 1 and 2 the releases were about 2 MCi/day).

The third stage was characterized by a rapid increase of fission product escape beyond the destroyed unit premises, which originated from the core fuel heating due to residual heat. Aerosols containing fission products were carried out with the graphite burning products. At that time the release was equal to 7-8 MCi/day.

The fourth stage, the last one, which started after the 6th of May, was characterized by a rapid effluent decrease. It was 0.1 MCi/day on May 6 and decreased to 2×10^{-5} MCi on May 23. The nuclide composition of the released fission products is shown in the Table 1.1.1.

1.2.4. Control over Radiation Situation

The control over the radiation situation was carried out directly by the service of external dosimeter and the subunit of the Plant Civil Defence. But neither the ChNPP administration, nor higher administrative bodies received objective information during the first hours of the catastrophe owing to bad readiness of the above services.

The first interdepartmental team of specialists arrived to Prypiat' to render help to the emergency ChNPP on April 26, and at once the team began to inspect the radiation situation (representatives from the Ministries of Energetic, Health, Defence of the USSR). Towards the evening of April 26, the level of radiation in Prypiat' was 14-130 mR/hour, and by the morning of April 27 it reached 180-500 mR/hour Toward the evening of April 27 the radiation level rose sharply reaching in different regions of the town from 400 till 1000 mR/h but in some places it amounted to 1.5 R/h. In Chornobyl the level for May was 24 mR/h On April 29,1986 they approved the decision to entrust the Commander of Chemical troops of the Ministry of Defence of the USSR with a mission of ensuring radiation monitoring in the adjacent 10-km zone, while beyond this area this mission was entrusted on the chairman of the Hydrometeorological Committee of the USSR (Goscomgydromet) Already the first measurements of the gamma radiation intensity at the ChNPP industrial site fixed the values up to 1000 R/h Deactivation of the industrial site, constructions and buildings of the ChNPP, as well as erection of the "Shelter" encasement, brought about an improvement of the radiation situation, the value of exposure dose rate (EDR) reduced to 1 R/h and later continued reducing.

Table 111 **Released radionuclide composition assay after the Chornobyl NPP accident ***

Nuclide **	Release activity, MCi		The activity released from the reactor by 06.05.86 %
	26.04.86	06.05.86***	
^{133}Xe	5	45	Probably, up to 100
^{85m}Kr	0.15	—	the same
^{85}Kr	—	0.9	the same
^{131}I	4.5	7.3	20
^{132}Te	4	1.3	15
^{134}Cs	0.15	0.5	10
^{137}Cs	0.3	1.0	13
^{99}Mo	0.45	3.0	2.3
^{98}Zr	0.45	3.8	3.2
^{103}Ru	0.6	3.2	2.9
^{106}Ru	0.2	1.6	2.9
^{140}Ba	0.5	4.3	5.6
^{141}Ce	0.4	2.8	2.3
^{144}Ce	0.45	2.4	2.8
^{89}Sr	0.25	2.2	4.0
^{90}Sr	0.015	0.22	4.0
^{238}Pu	1×10^{-4}	8×10^{-4}	3.0
^{239}Pu	1×10^{-4}	7×10^{-4}	3.0
^{240}Pu	2×10^{-4}	1×10^{-3}	3.0
^{241}Pu	0.02	0.14	3.0
^{242}Pu	3×10^{-7}	2×10^{-6}	3.0
^{242}Cm	3×10^{-3}	2×10^{-2}	3.0
^{239}Np	2.7	1.2	3.2

* Evaluation error reaches 50 %
** Only the data on basic radionuclide activity measured in the course of radiometric analyses being included
*** Total release by 06.05.86

Beyond the limits of the adjacent 10-km zone the maximum levels of radiation during the first days were fixed by the control network and aviation means of the USSR Hydrometeorological Committee in some areas of the Kyiv and Zhytomyr regions of Ukraine, Gomel and Mogilev regions of Belarus, Bryansk, Tula, Kaluga, Oriol regions of Russia.

According to the first report of the Goscomhydromet of the USSR (April 27, 1986), the gas stream was 40-50 km long and 15-25 km wide in the North and in the North-West directions (with radiation levels from 2 to 5 mR/h). It was also noted that the later spread of air masses from the region of the catastrophe was expected in the North and North-West directions. But on April 28 the meteorological conditions changed and air masses were transferred in the East and South-East directions, later turning to the North.

The first map of contamination was produced for the Government Committee on May 3, 1986, since it became possible to evaluate separately effects of the gas-aerosol current and contamination of locality.

The map of radiation levels for all the European territory of the country was drawn, basing on the results of air photography carried out from April 30 till May 7, 1986.

The results of daily air photography and measurements formed the basis for a generalised map of EDR of gamma radiation which was prepared by May 10, 1986. This map served supported the process of evacuation of population.

Following the suggestion of the USSR Ministry of Health and Goskomhydromet, the estrangement zone was defined at that time as the territory with EDR of gamma radiation > 20 mR/h; the zone of complete population removal had EDR > 5 mR/h and the zone of hard control with temporary removal of children and pregnant women had that with EDR from 3 to 5 mR/h.

The first maps of radioactive contamination density of the area by ^{137}Cs, ^{90}Sr and $^{239, 240}Pu$ were made by Goskomhydromet of the USSR in June 1986, after a wide series of measurements made in the localities by airgammaspectrometry.

Taking into consideration the large area of contaminated territory and their "spotted" structure, the detailed stage by stage elaboration was carried out, and the first maps were added and grew more detailed and precise.

1.2.6. Evaluation of Radioactive Contamination Extent for the Environment within the Zone of the ChNPP Accident Influence

The wind distributed the radioactive releases over the territory of Ukraine, Belarus and Russia. The first current of radioactivity and the radioactive cloud were divided into two parts and moved in two directions - to the West and to the South. The towns of Piypiat' (45000 of the population, 3 km away from the NPP) and Chornobyl (20000 of the population, 12 km away from the NPP) turned out to be between the flows and, consequently, exposed to contamination in the smaller degree than, for example, the "red forest" where levels of the radiation fields were 100 R/h at the distance of 2 km from the NPP. The power levels of radiation fields in Prypiat' town did not exceed several scores mR/h before the evacuation. The same was in Chornobyl, where average levels of gamma radiation (May 1986) were from 10 to 20 mR/h. It is quite easy to imagine how vast would have been the tragedy extent if the first cloud had passed over Prypiat' town and Chornobyl.

Three days later, on April, 29 1986 the wind turned to the South and the radioactive cloud began to move towards Kyiv. By that time the power of releases from the reactor had essentially fallen (approximately five times in comparison with April 26, 1986, the Table 1.1.2). It had led to rather lower radiation levels in Kyiv; on an average 1.5 mR/h on April 30 and 0.6 mR/h on the lst-2nd of May 1986 (in some places the dose was higher, for example, on Nauka Prospect -2.2 mR/h). Then the radiation level began to fall.

When the power of releases rose again after the 2-nd of May (the Table 1.1.2), the wind direction changed to the South-West, then North-West and to the North. Such directions of the wind brought as a result diminishing of the radiation attack during the first 10 days after the accident in Prypiat', Chornobyl and Kyiv, compared to that theoretically possible. Unfortunately, some of the settlements situated to the.South and East of the ChNPP turned out to be in the zone of hard radiation. The contamination of Ukrainian, Belarusian and Russian territories conventionally can be divided into three traces: Northern, Western and Southern.

At present the main doseforming elements are caesium, strontium and plutonium. Caesium plays the main part. Strontium and plutonium are mainly found within the 30-km ChNPP zone. Contamination of the territories is shown in the Table 1.1.3. The Table 1.1.4 represents the data about number of the inhabitants residing on the contaminated territory.

Territories of the European countries, Austria, Bulgaria, Hungary, Italy, Norway, Poland, Romania, England, Turkey, Greece, Germany, Finland, Sweden, Yugoslavia, are much less contaminated.

Specialists from certain departments of the USSR (Goskomhydromet, Ministry of Defence, Ministry of Health and the Academies of Sciences of the three Republics) produced maps of the environmental radioactive contamination by July - August 1986. These maps were considered secret and were utilized by the government offices only. The maps were published in the newspapers, brochures and became accessible for wide sections of the population in May 1989. The data of 1986 mostly remained unchanged after some verifications which were made since 1987 till 1990.

Outside the ChNPP industrial site, the average release of all the radionuclides to the territory of the USSR composed ≈3.5% of the total quantity of decay products which theoretically were inside the IV power unit during its operation.

Table 1.1.2

Daily radioactive substance release (Q) from the emergency unit into the atmosphere (Radioactive noble gases excluded*)

Data 1986	Post-accident time, days	Q, MCI**	Data 1986	Post-accident time, days	Q, MCi**
26.04	0	12.0	03.05	7	5.0
27.04	1	4.0	04.05	8	7.0
28.04	2	3.4	05.05	9	8.0
29.04	3	2.6	06.05	10	0.1
30.04	4	2.0	09.05	13	0.01
01.05	5	2.0	23.05	27	20×10^{-6}
02.05	6	4.0			

* Release evaluation (Q) error reaches ±50%. This is due to the dosimetric gauge deviations, errors in radiometric measuring of the radionuclide composition in the air and soil samples, as well as the errors caused by the area fallout averaging.

** The values of Q being recalculated for May 6, 1986, taking into account radioactivity decay (On April 26, 1986 the activity release constituted 20-22 MCi)

Table I. J. 3 **The area of territories contaminated by ^{137}Cs, thousands ha.**

Republic	Degree of contamination, Ci/km^2			Total
	5-15	15 -40	40	
Russia	454	235	36	725
Ukraine	235.5	74	68	377.5
Belarus	720.2	406	221	1347.2
Total	1409.7	7.5	325	2449.7

Table LI A **The number of inhabitants in the contaminated territories, thous. of persons**

Republic	Degree of contamination, Ci/km^2				Total
	to 5	5-15	15-40	40	
Russia (the Bryansk region only)	109.0	73.5	109.7	5.2	297.4
Ukraine	1227.3	204.2	29.7	19.2	1480.4
Belarus	1734.0	267.2	94.6	9.4	2105.2
Total	3070.3	544.3	234.0	33.8	3883.0

3.1. Natural Conditions in the Disaster Active Influence Zone

3.1.1. Meteorological factors in formation of the initial radioactive contamination field

In parallel with the factors governing the intensity and the character of the radioactive ejection from the ruined Chornobyl NPP IV unit, the radioactive contamination field was governed by the meteorological factors that controlled formation of the initial radioactive contamination field over vast squares both near the plant and in the remote areas.

At burning of the Chornobyl IV unit radioactivity entered the atmosphere as a hot turbulent jet which contained the radioactive gases and aerosol particles. It decreased as a result of heating and was transported with wind to the boundary atmospheric layer where both the direction and velocity of wind were dependent on the altitude. As colder atmospheric air mixed in, the temperature of the jet fell, the velocity of its ascent reduced, its radius extended, and concentration of radioactivity decreased. Thus in the near-field of the contamination source only the coarse aerosol particles might fall which were to overcome ascending current of the air. As the current became weaker, smaller particles fell out. In the turbulent flow the particles moved downwards due to the turbulent transport, which may be faster than a free fall in case if the thermal gradients would be sufficiently high. Due to a high initial overheating as compared to the ambient air, the jet was rising within a few minutes, i.e. it reached its highest position at a 10 to 15 km distance from IV unit; its temperature became equal to that of the ambient air, and the jet occupied the major part of the atmospheric boundary layer. As long as concentration of radioactivity in the jet remained sufficiently high, radioactivity deposited onto the ground. At the same time the jet followed the variations in the direction and velocity of wind.

Radioactivity ejected from the burning unit varied in time, and the amount of fallout, governed by the two factors, was also dependent on the wind direction and distance from the source. All that resulted in a general non-uniform (spotted) pattern of the radioactivity field on the ground. In addition to the factors governing the sufficiently large-scale spots (macrostructure), the small-scale spots were formed as a result of interaction between the turbulent flow of the radioactive particles and soils covered with variable vegetation, similar to the processes at formation of a thin snow cover. One of the mechanisms governing the large-scale spotty pattern will be discussed below.

Radioactivity deposition on the ground decreased with concentration in the moving cloud, and the latter was carried away by wind to large distances.

Long-range transportation of radioactivity. To study the spread of the radioactive cloud over the long (planetary-scale) distances advantage was taken of a method for calculation of air particle ways based on the known observed wind field. Since both the velocity and direction of the wind depend on the altitude, then the air particles, moving at different altitudes, might follow the different ways resulting in the "splitting" of the radioactive cloud. The spread of the radioactive cloud could be affected by such atmospheric phenomena as cyclones and atmospheric fronts.

At the period of IV unit burning the synoptic (weather) situation was sufficiently variable, characteristic of a spring. At the instant of the accident the weather in the vicinity of the Chornobyl NPP was governed by an anticyclone centred at the Urals that was stretched in the SE - NW direction. The circulation was cyclonic in nature to the west and north-west of the anticyclone, whereas the southern regions, the areas situated between the cyclone in the West and North Europe and the anticyclone, were influenced by the low-gradient baric field. Later on, the anticyclone was displaced in the SE direction, and its location was occupied by a low-gradient field with a few small baric formations. To illustrate, in the morning of April 27, 1986, a small cyclone was centered south of Gomel. All this was followed by a radical rearrangement in circulation. The anticyclone formed over Central Europe was shifted northwards and by May 3, 1986, it was converted into a high-pressure ridge centered at the Baltic region. Later on, the high-pressure area was shifted south-westwards, covering the western and south-western parts of the European territory of the USSR, and cyclonic activity proceeded south-eastwards. Then southern and south-western parts of the European territory of the USSR occurred for a long period in the zone influenced by an anticyclone centred in Minsk, and as a result, the central part of Ukraine was free of heavy precipitation.

Time variation of the wind field conforms sufficiently well to the described evolution in the synoptic situation [3,39]. Research into the radioactivity propagation ways was carried out in different countries. According to the analysis [3] six periods of the radioactive fallout may be identified within the period of FV unit burning (from 26.04 to 6.05 1986): (1) from the beginning of the accident until 12.00 26.04 the radioactive cloud advanced towards Belarus, Lithuania, the Kaliningrad Region of Russia, Sweden and Finland; (2) from 12.00 26.04 to 12.00 27.04, towards

Polissa, Poland and further south-westwards; (3) from 12.00 27.04 to 29.04 towards Gomel, Bryansk and further eastwards; (4) 29.04-30.04 towards Sumy, Poltava regions and further towards Romania; (5) 1.05-3.05, towards the South of Ukraine and across the Black Sea towards Turkey; (6) 4.05-6.05, towards West Ukraine, Romania, and after a turn in path towards Belarus.

The synoptic maps and the areas of radioactive fallouts in Europe, for each day of the reactor burning are shown in the Fig.I.3.1. As can be seen, the fairly simple compact areas of radioactive fallouts characteristic of the initial post-accident period are becoming more and more complex, pushing apart and taking very intricated arrangement. To illustrate, characteristic is the Fig.I.3.2, that shows "the travel" of the radioactive cloud shifting west-north-westwards on 26.04.1986. On 28.04.1986, it turned south-westwards, reached Bavaria, then crossed France, England without radioactive precipitation, after that above the Atlantic it was entrained into cyclonic circulation, re-entered England, and than got to the area of precipitation formation, fell onto the ground as a radioactive rain on the 7-8th of May, and then left for Scandinavia (the Fig.I.3.2).

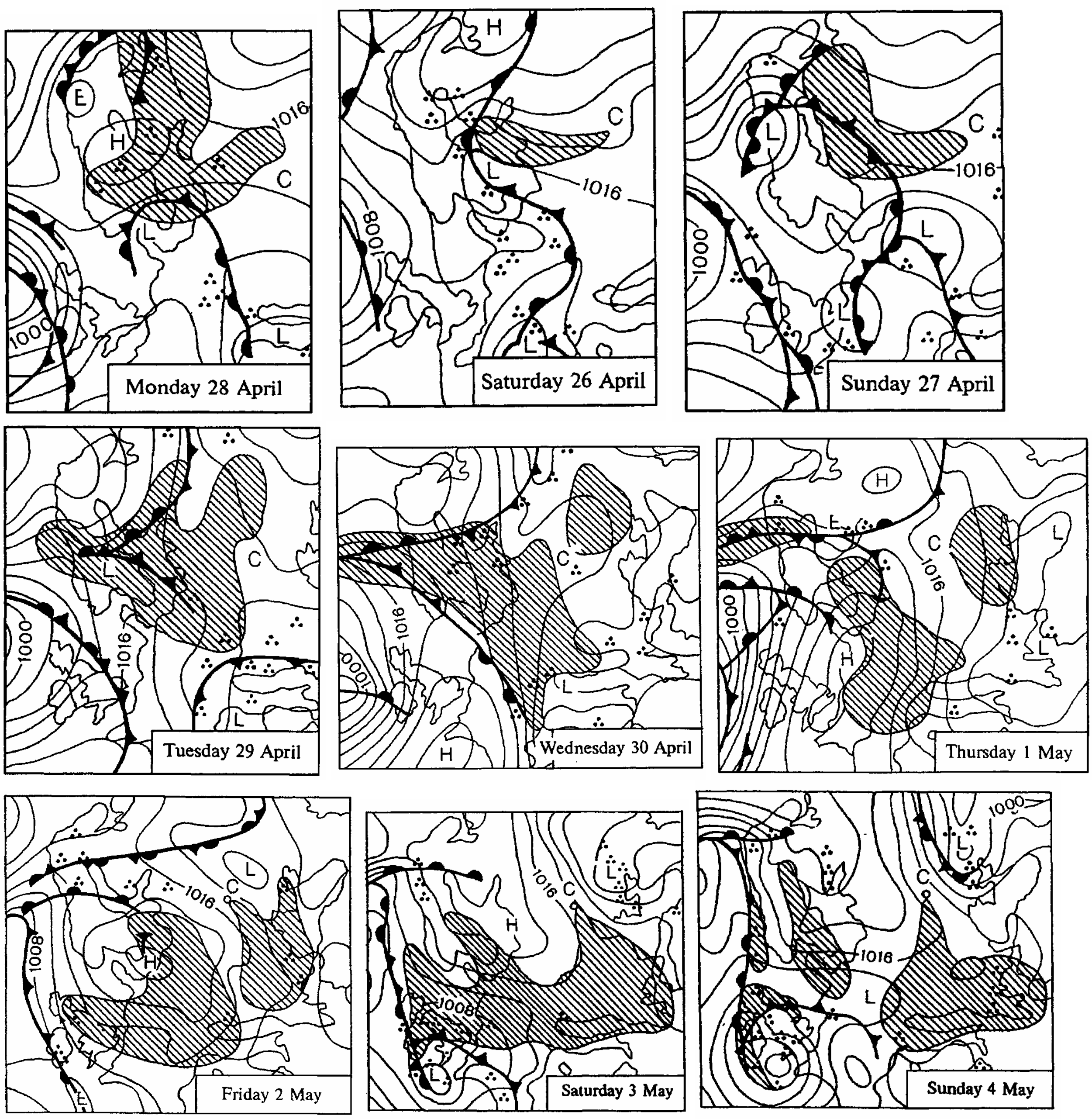


Fig. L 3.1. Synoptic situation with indicated precipitation and the pattern of radioactive fallout for each of the post-accidental days [2]: Saturday, April 26; Sunday, April 27; Monday, April 28; Tuesday, April 29; Wednesday, April 30; Thursday, May 1; Friday, May 2; Saturday, May 3; Sunday, May 4; Monday, May 5; Tuesday, May 6; Wednesday, May 7; Thursday, May 8. Chornobyl. The areas of radioactive fallout hatched being obtained from the trajectory of the cloud and radiological measurements

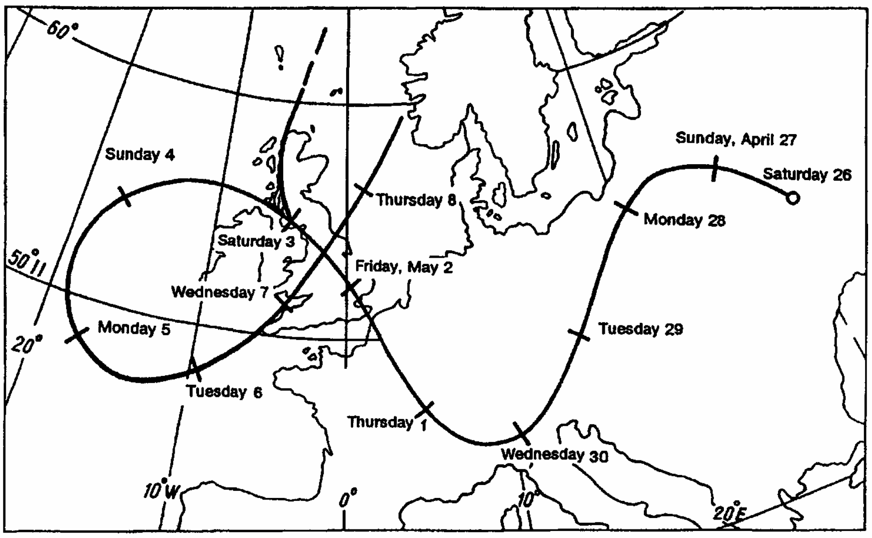


Fig.1.3.2. Trajectory of the radioactive cloud that crossed England. Locations being shown for each post-accidental day, 12.00 GMT: Above England the cloud moved around the depression towards south-east of England, and then next week crossed England again with a lower content of radioactivity. Further on the cloud continued to move north-eastwards over the Norwegian Sea 1391

Medium-scale formation of the radioactive "trace". Besides, different "traces" related to changes in the wind direction, the field of initial radioactive contamination exhibits an additional feature not characteristic for usual diffusion: contaminants from the sources. They include existence of gaps and individual "islands" with enhanced radioactivity levels: e.g. as such an island in the southern "trace" may be considered a spot in the Uman - Korsun-Shevchenkivsky region, a large spot in Bryansk and Orel regions of Russia, separated from the rest of the contamination field. It may be explained as a result of diurnal variations in the parameters of the atmospheric boundary layer. In warm seasons, at night the soil surface gets rather cold and the air temperature rises with altitude, that causes weakening of the turbulent transportation of contaminants towards the ground surface. Thus, a contaminant ejected at night, reached the earth's surface at a more remote location from the source. In the day-time the air temperature decreased with altitude (unstable stratification), turbulence became more active, and a contaminant reached the earth's surface at a smaller distance. As a result, radioactivity entered the atmosphere in the day-time on 28.04,1986, formed a radioactive spot north of Gomel; a night ejection on 29.04.1986 gave maximal contamination 400 to 500 km from the NPP along the Bryansk-Orel direction. The same explanation may be given to the rest of the "islands" of radioactivity (the Fig.I.3.3) [4].

An important factor influencing formation of the initial radioactive contamination is the change of the wind direction with altitude, especially pronounced in the boundary atmospheric .layer. Since the particles of the radioactive cloud fall with different velocities under gravity, the particles of different size will be possibly concentrated at different altitudes, and shifting of the wind direction with altitude will lead to falling out the size-different particles at various areas of the earth's surface, favoring emergence of radioactive spots. Change of the wind direction with altitude may also result in spreading of the radioactive cloud in different directions. The trajectories of the clouds started from different altitudes over the Chornobyl NPP at 12.00 GMT on 27.04.1986 are shown in the Fig.I.3.4. At the lower atmospheric levels (300 m) the cloud moved with wind north-eastwards, at 700 m to north and north-westwards, at 1500 m to westwards. At 3000 m at the initial stage the air mass was shifted westwards, but after 200-250 km it turned sharply southwards, and further on it moved eastwards.

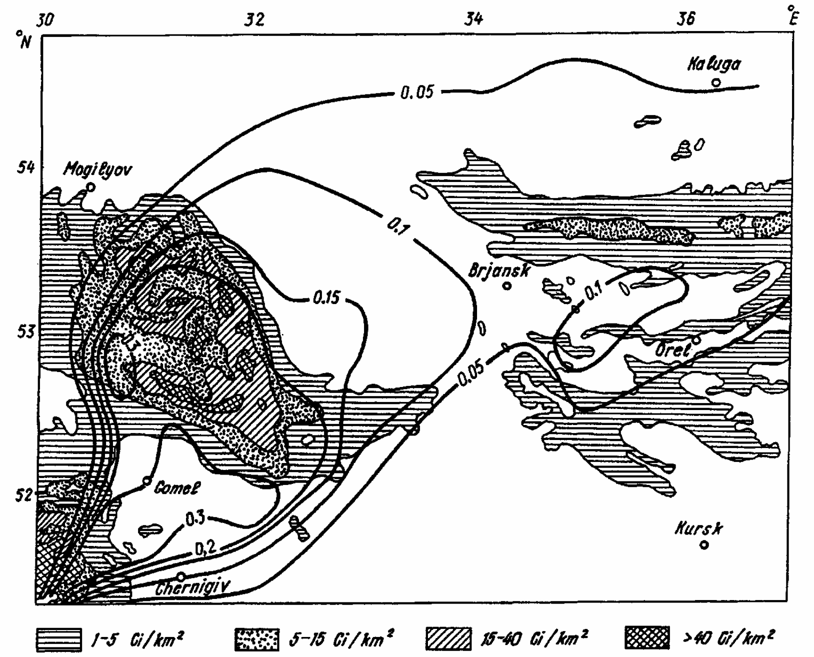


Fig. 1.3.3. Observed (hatched) and calculated fields of ground radioactivity for the eastern trace emerged on the 28-29th of April. Figures at the contour lines - Ci per km^2 [3]

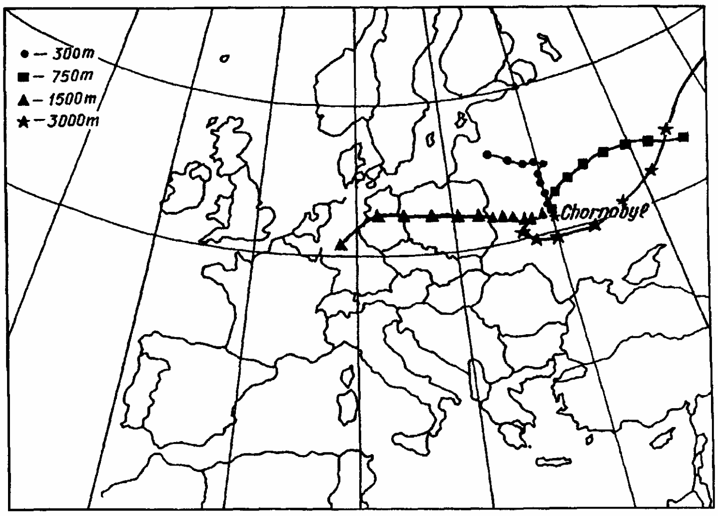


Fig. 1.3.4. The calculated trajectories of the radioactive cloud, started to move on April, 27 at 12.00 GMT at different altitudes in the boundary atmospheric layer. Spacing between the points corresponds to 6 h time intervals [46]

Thus, the meteorological factors of formation of the radioactive contamination field were characterized by a sufficiently complex spatial structure and time variability. Undoubtedly, all this resulted in a complex, spotty pattern of the radioactive fallout, not completely revealed up to now and requiring further research.

3.1.2. Physico-Geographical Conditions and Landscape-Geochemical Features

At the initial stage, the field of radioactive contamination resulted from the Chornobyl fallout was formed under the influence of such landscape factors as surface topography, plant cover, hydrographic system, and the mode of economical development of lands.

When entering the environment, artificial radionuclides are incorporated into the natural mass- and energy exchange processes which are complex by their very nature and cover all the principle components of the environment, including aqueous, atmospheric, and biogenic transport. Thus, the type of geochemical conditions, as well as the intensity of migration processes vary depending on a pattern and dynamics of landscapes within a contaminated area.

The landscape pattern in the accident's zone is governed by its position in the Ukrainian Shield, including its NE and W slopes, on each side of the boundary of the Dnipro Quaternary Glaciation, in the zone of mixed forests. The climatic features of the area are formed, primarily, by the Atlantic cyclones responsible for formation of moderately cold winters (average temperature of January is -5° and -6°C) and moderately warm summers (average temperatures of July is +17° and +19°C). Average annual precipitation equals 580 mm, of which three thirds fall on the warm season. For individual months the precipitation may reach 140-150 mm and more.

In the zone of relocation, or the abandoned zone, that for the bigger part coincides with the circular 30-km zone around the Chornobyl NPP, the landscapes are represented by the till fluvioglacial, limnoglacial, and alluvial plains, ranging in their elevation, landforms, and lithology of superficial and subjacent deposits (See the Fig. 1.3.5). All this dictates nonuniformity, or even variation in the soil and plant cover, and as a consequence, variability of the landscape and geochemical conditions.

The principal relief level in the regions of Kyiv and Zhytomyr Polissa (woodland) along the western "trace" of the radioactive cloud is represented by the till fluvioglacial plain with elevations exceeding 120 m, composed of a deposited till of the Dnipro age (boulder loams, compacted, sticky, enriched with sand particles) and fluvioglacial sands, fine-grained, well graded, 0.8 to 2.5 m thick. The area with its soddy-slightly podzolic gleization-variable soils is covered with pine forests with minor oaks, locally cleared and replaced by agricultural plants. As to the exclusion zone, the agricultural lands were abandoned after economic activity was terminated. At present they restore their zonal plant cover.

Against the background of the till fluvioglacial plain typical of the near-field Chornobyl zone we should distinguish such uplands as Chistogalivka end-moraine ridge and Ovruch erosion-denudation range. The former occurs as, at least two chains of end-moraine hills, with gentle (2-4°) and smooth (4-6°) slopes separated by saddles and lows. The upland is composed of the boulder loams of thrust