Scenario for modeling changes in radiological conditions in contaminated urban environments

Pripyat, Districts 1 and 4

Phase A: Undisturbed urban environment with no human activity
Phase B: Urban environment with human activity
Phase C: Urban environment with effects of remediation activities

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Contents

Additional information (Excel workbook)

I. Introduction

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 is based on Chornobyl (Chernobyl) fallout data for Pripyat, a town in Ukraine which was evacuated soon after the Chornobyl accident and has remained essentially uninhabited.

The scenario is designed to allow modeling in three phases. Phase A provides an opportunity to model the changes over time of external exposure rates and concentrations of radionuclides in different compartments of an urban environment due primarily to natural processes. This phase uses information on District 1 of Pripyat. Phase B provides an opportunity to model changes over time of similar endpoints in a situation that includes the effects of human activity. This phase uses information on District 4 of Pripyat, which was inhabited for a time after the Chornobyl accident. Phase C provides an opportunity to model the effects of various remediation efforts on the changes over time of the radiological situation. This phase also uses information on District 4 of Pripyat.

A set of input information (measurements of deposition and of radionuclide composition) are provided for use for all phases of the scenario, to provide a common starting point. Some additional data are provided for use in model calibration for participants desiring to do so. Test data (measurements) are available for some modeling endpoints; additional endpoints will also be used for model intercomparison.

This document provides information about the situation to be modeled (input information) and a list of the endpoints to be modeled. Note that all tables are provided in an accompanying Excel workbook. Data in GIS format (MapInfo or ESRI formats) are also available.

II. Background

In the context of urban radioecological study, the main interest is what radioactive fallout resulted, and when and where it fell out during 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 [Baryakhtar, 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 [Izrael, 1990; Baryakhtar, 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 [Izrael, 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 10-100 μm) and were deposited along the first kilometers of the cloud's path [Kashparov, 2001]. Also, at the moment of the explosion, almost all of the reactor's noble gases were released into the atmosphere [Izrael, 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 [Izrael, 1990; Baryakhtar, 1997], bending around 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[1] reached 0.1-0.6 mR/h there (in some places, 2.0 mR/h) [Nad'yarnyh et al., 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 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 [Baryakhtar, 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 during that time the releases were enriched by small particle aerosols with sublimated radionuclides, there were also some heavy combustion products 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 [Izrael, 1990].

Because of a considerable decrease of reactor core temperature, the intensity of the radioactive releases gradually dropped by April 30 (up to 6 times [Izrael, 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 contributed to 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

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[1] For purposes of this scenario, assume that "R" refers to Roentgen for measurements made in 1986 and to Rad for measurements made in 1987 or later.

fallout lay to the south [Izrael, 1990]. That continued till May 6, 1986, when the intensity of the releases dropped to 1% of the initial amount and less. Further radioactive releases continued to decrease, and had almost ended by May 25, 1986 [Izrael, 1990].

Thus, the Chornobyl accident and the following spread of radioactive releases caused contamination of broad territories in Europe, including several urban areas. Deposition from the accident contained a wide spectrum of nuclear fission products, activation products, and transuranium elements. Fallout in the town of Pripyat was mainly in the form of finely dispersed fuel. 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 et al., 2003][2]. Deposition data for the specific districts of Pripyat considered in this scenario are discussed later.

II.1. Description of the town of Pripyat

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 (13,500 flats and up to 30,000 rooms). The total length of underground communications is 135 km, including 52 km of heating main. The area of industrial premises is 30,000 m^2, and of other non-residential buildings, 10,000 m^2 [Nad'yarnyh et al., 1989].

All of the population (up to 49,360 at the time of the accident) was evacuated in 1986 as a result of accidental radioactive contamination, and the town has 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 an area of restricted access.

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. 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 include 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 time of the accident, the sands had no surface fixation). The town had railway, river and developed road communications with other regions.

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[2] Another source [Garger et al., 1996] gives the following information (MBq/m^2) for the density of surface soil contamination in Pripyat (4 km from the source of contamination), measured in the summer of 1986: ^{144}Ce, 55.5; ^{141}Ce, 4.4; ^{103}Ru, 4.85; ^{106}Ru, 14.43; ^{137}Cs, 5.22; ^{134}Cs, 1.96; ^{95}Zr, 28.7; ^{95}Nb, 53.7. These values represent at least 3 samples 15 cm in diameter, taken to a depth of 5 cm.

II.2. 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 (Fig. 1), 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; 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 industrial areas. The town has a developed system of industrial and storm sewage, road network, and other communications.

II.3. 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.

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). 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).

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 [Izrael, 1990].

After the population was evacuated, natural transformation processes of vegetation cenosis began. 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 and Bednaja, 1998]. Humidity has increased in most of the forest districts.

II.4. 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. 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.). 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.

Figures 2 and 3 show the layout of the buildings in Districts 1 and 4, respectively, of Pripyat and the number of stories in each building. Table 1[3] contains additional information on the buildings in Districts 1 and 4, including the heights, type of use (e.g., apartment house, school, etc.), and types of materials.

II.5. 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.

[3] All tables are found in the accompanying Excel workbook.

III. 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 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 [Baryakhtar, 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 (26 April-30 June 1986), for the Chornobyl meteorological station, is provided in Table 2; additional meteorological data are provided in Tables 3-9.

The first observation point network was established by ChNPP radiation protection service officers. These data included 26 points located in the town of Pripyat (Figure 4). 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 was formally accepted about 12:00 27.04.) Isolines of dose rate at each time point, based on these data, are shown for the whole town of Pripyat (Figs. 5-8). The data for the observation points are given in Table 10. For the isolines, values of the dose rates in and near Districts 1 and 4 of Pripyat are provided with coordinates in Tables 11-14 (information to correlate the map coordinates for the isolines with latitude and longitude is provided with Table 11).

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 made measurements in some local areas of the Zone (especially in the town of Pripyat) during the summer of 1986 (probably mid-June to the beginning of July). Some sets of data from this team are available, but the notes from this expedition have not been located. The data obtained by this team for Districts 1 and 4 of Pripyat are given in Figures 9 and 10 and Table 15.

IV. Decontamination activities

Decontamination efforts in Pripyat are considered in Phase C of this scenario. Some decontamination activities were carried out for the whole town of Pripyat, but the most extensive decontamination efforts were applied primarily in District 4. Details of the decontamination efforts are provided below. A summary of the decontamination activities carried out in various areas is provided in Table 16; the areas are shown in Figure 11.

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 and a surface-active additive. Road surfaces (asphalt, concrete, etc.) were treated with clay solutions, which were then washed. Levees were built on the river bank along the northeastern and northern border of the urban area. During periods of intensive decontamination, the industrial and storm sewer systems were plugged to prevent drainage of radioactive materials 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 (over a few days) in the beginning of May 1986 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 (Site 1 in Fig. 11 and Table 16).

Some days later (11.05.86) a decision was made to conduct test decontamination of some buildings. On 14.05.86 the first three buildings in micro-district # 4 were experimentally decontaminated to define a more successful method of decontamination [Karataev et al., 1989a, 1989b]. 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.

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 (Sites 2 and 4 in Fig. 11 and Table 16, including 9 residential buildings, two kindergartens, a school, and 2 dormitories later used for accident staff) 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, 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 also decontaminated.

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; includes Sites 8 and 12 in Fig. 11 and Table 16). 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 accident staff. The following buildings and working areas were restored (including Sites 3, 8, 9, and 10 in Fig. 11 and Table 16): Special Enterprises 'Complex' (former building of city administration and some others), Enterprises 'Specatom' (former instrument-making plant 'Jupiter'), Department of dosimetry control (buildings of former technical school, and Lab of external dosimetry), 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; up to 110,000 m^2 of building outdoor surfaces were cleaned, 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 for at least 10 years after the accident.

Some areas surrounding Pripyat to the east, south and southwest (Sites 12 and 13 in Fig. 11 and Table 16) 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, including 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 the area 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 the 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), the total concentration of beta-emitting radionuclides in air was approximately 10^{-5} Bq/m^3, and of 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 (Table 17). The radionuclide concentrations in air at the two automatic radiation control posts ('Stadium' and Lab of external dosimetry) during the 1989-1991 period are given in Table 18.

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].

V. Input information (deposition data)

Deposition information for Districts 1 and 4 of Pripyat is provided in Table 19. Vertical distributions of activity in soil for the samples in District 1 are given in Table 20. These data should be used as the starting point for calculations for the Pripyat scenario. Table 19 contains information on radionuclide content in the top layer of the soil, converted to units of MBq/m^2. Table 20 contains information on the vertical distribution of radionuclides, for the same District 1 samples used in Table 19. Note that the information in Table 20 is still in units of Ci/kg of soil.

VI. Additional data for use in calibration

Two additional sets of data are provided for use in calibration, if desired. The first of these consists of detailed measurements of activity on several buildings in District 1a of Pripyat (very close to District 1) in October 1986. A description of the situation, including detailed diagrams of the buildings and sampling points, is provided in the Appendix of this document, including Table A-1 (in the Excel workbook). Details of the measurements are provided in Table A-2.

The second data set consists of the results of an air gamma survey (^{137}Cs, Bq/m^2) performed in 1991. These data are given in Table 21 and Figures 12 and 13 for Districts 1 and 4 of Pripyat. Table 21 gives the calculated values of ^{137}Cs density of contamination for a grid size of 50×50 m.

VII. Modeling endpoints

The modeling endpoints for Districts 1 and 4 of Pripyat are as follows:

(1) external exposure rates (dose rates, mGy/h) at specified locations, from all relevant surfaces;

(2) contributions to the dose rates from each surface, for the most important surfaces;

(3) annual and cumulative external doses (mGy) to specified reference (hypothetical) individuals (Phase C only); and

(4) radionuclide concentrations (Bq/m^2) at the outdoor locations.

Model calculations should start about 3-4 months after the Chornobyl accident and should be carried forward for at least 10 years, preferably 20 years. Results should be presented as a time series, with the date specified for each predicted dose rate, dose, or radionuclide concentration. Example formats are provided in the accompanying Excel workbook, for each Phase of modeling as described below.

For dose calculations (Phase C only), use the following (hypothetical) reference individuals:

(1) an adult, employed in indoor work;

(2) an adult, employed in outdoor work;

(3) a pensioner;

(4) a child, attending school or kindergarten; and

(5) a pre-school child.

Suggested occupancy factors are provided in Table 22. Assume that the individuals lived and worked in District 4. For reference children, predictions of annual dose are requested; for reference adults, annual and cumulative doses are requested.

All endpoints will be used for model intercomparison. Test data (measurements) are available for a few locations and time points, which will permit comparison of model predictions and measurements for selected situations.

VII.1. Phase A

For Phase A, the purpose is to model the changes over time of external exposure rates and radionuclide concentrations due to natural processes alone (no human activity, no remedial measures). For this phase, calculate the external exposure rates (mGy/h) and radionuclide concentrations (Bq/m^2) at nine specified locations in District 1 (Fig. 14; map positions are given in Table 23). Locations 1, 2, 5, and 6 are outdoors, two of them next to a road, one on a natural surface, and one on an artificial surface. Locations 3 and 4 are indoors in schools. Locations 7, 8, and 9 are on the 1st, 3rd, and 5th floors of a 5-story apartment building.

VII.2. Phase B

For Phase B, the purpose is to model the changes over time of external exposure rates and radionuclide concentrations due to natural processes and human activity (no remedial measures). For this phase, calculate the external exposure rates (mGy/h) and radionuclide concentrations (Bq/m^2) at five specified locations in District 4, outside the areas where remedial activites were implemented (Fig. 15; map positions are given in Table 23). Locations 10, 11, and 12 are indoors on the 1st, 5th, and 7th floors of the unfinished end of an apartment building. Locations 13 and 14 are outdoors, one on a natural surface and one on an artifical surface.

VII.3. Phase C

For Phase C, the purpose is to model the changes over time of external exposure rates and radionuclide concentrations due to natural processes, human activity, and specified remedial measures. For this phase, calculate the external exposure rates (mGy/h) and radionuclide concentrations (Bq/m^2) at ten specified locations in District 4 (Fig. 15; map positions are given in Table 23). These locations are within the areas where remedial activites were implemented (Sites 2 and 4, Fig. 11) and where people lived for several years after the accident. Also calculate the doses to reference individuals, assuming that people had lived in District 4 for the entire period covered by the model calculations.

Locations 15, 20, 21, and 22 are outdoors; two of these are on natural surfaces, one on a road, and one on an artificial surface outside a kindergarten. Location 16 is indoors in a 1-floor kitchen. Locations 17, 18, and 19 are on the 1st, 5th, and 9th floors of a 9-story apartment building adjacent to the kitchen. Locations 23 and 24 are on the 1st and 2nd floors of a 2-story kindergarten building.

The remedial measures (countermeasures, remediation measures) to be considered are listed in the table below, together with the time of application to be assumed.

	Countermeasure	Time of application (after the accident)
1	Washing of roads	First 2 weeks
2	Washing of roofs and walls	First 2 weeks
3	Cutting and removal of grass	First 2 weeks
4	Removal of trees	First 6 months
5	Removal of soil (15 cm)	First 6 months
6	Fixation in soil	First 6 months
7	Ploughing (50 cm)	First 6 months
8	Peel off coatings	First 6 months
9(a)	Relocation of population (temporary):	2 weeks
9(b)		6 weeks
9(c)		6 months

For each test location and each applicable countermeasure, calculate the dose rates and radionuclide concentrations first without any countermeasure and then with the indicated countermeasure. For dose calculations, predict the annual doses to each reference individual without countermeasures and then with the indicated countermeasure, assuming that the person lived and worked or went to school in District 4.

Information on effectiveness of various countermeasures is available in documents prepared by B. Zlobenko and S. Golikov (distributed separately from this document) and in other literature.

VII.D. Documentation of model predictions

For each phase of model predictions, appropriate documentation should be provided, including key assumptions and specific parameter values used. A format has been provided (Appendix III of the Working Group's draft report, distributed separately from this document). For Phase C, for each countermeasure (or combination of countermeasures, if appropriate), please include a description of how the countermeasure was modeled and provide the parameter value(s) used.

VIII. References

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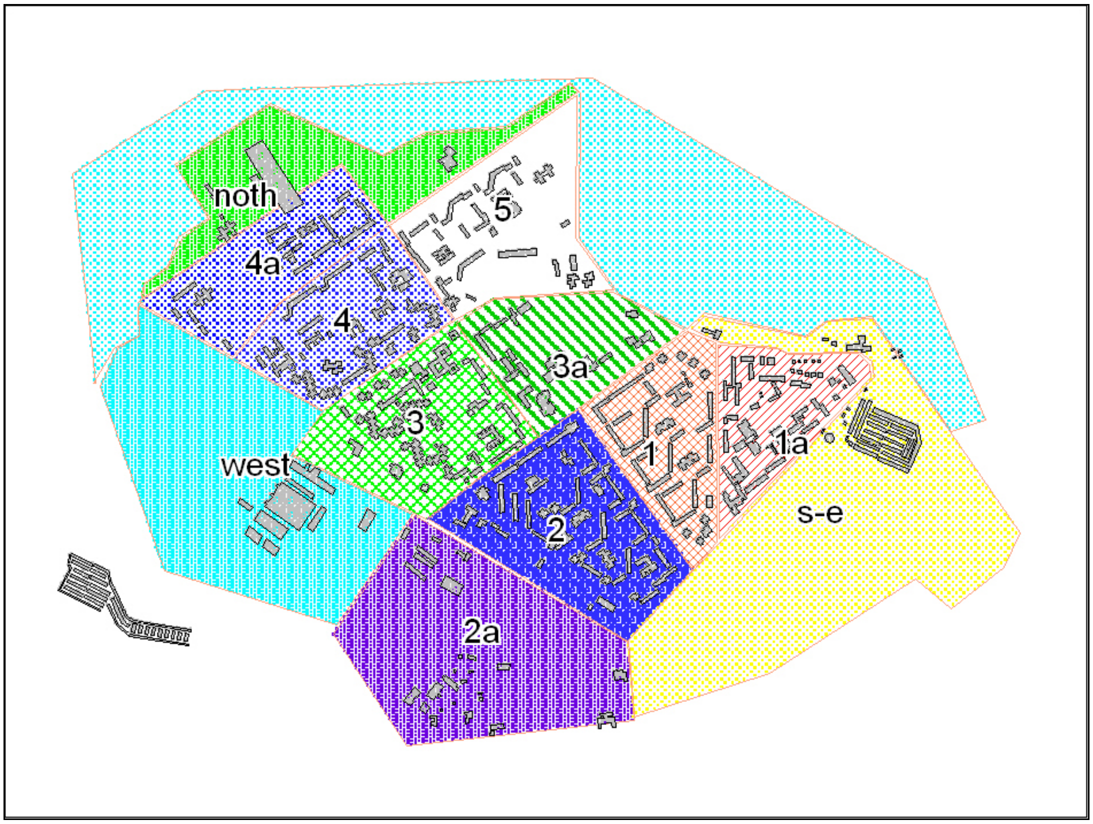


Figure 1. Map of microdistrict locations in the town of Pripyat.

Figure 2. Map of District 1 of Pripyat, showing building locations and heights. Buildings are listed by number in Table 1.

Figure 3. Map of District 4 of Pripyat, showing building locations and heights. Buildings are listed by number in Table 1.

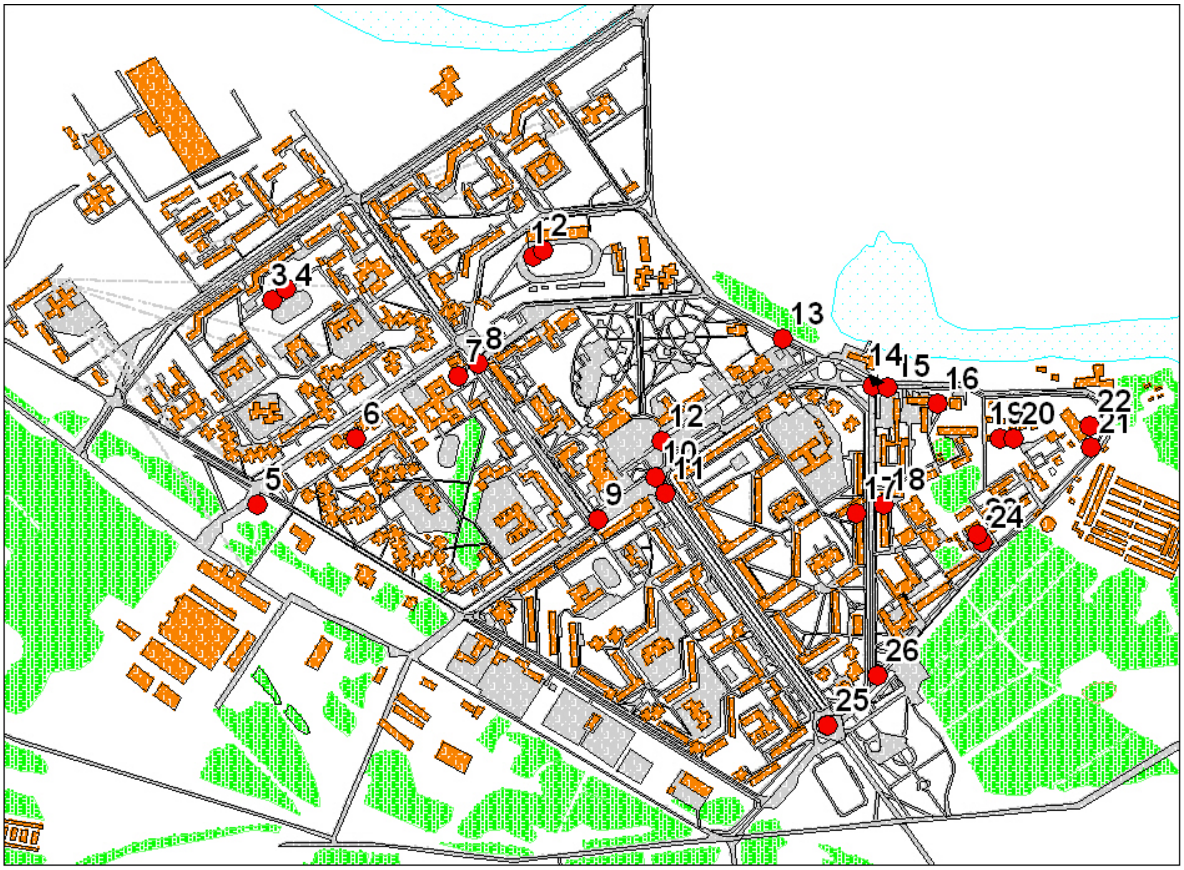


Figure 4. Locations of the observation points in Pripyat for measurements made during 26-27 April 1986. Data obtained at these points are provided in Table 10. Isolines derived from these measurements are shown in Figures 5-8 and the data provided in Tables 11-14.

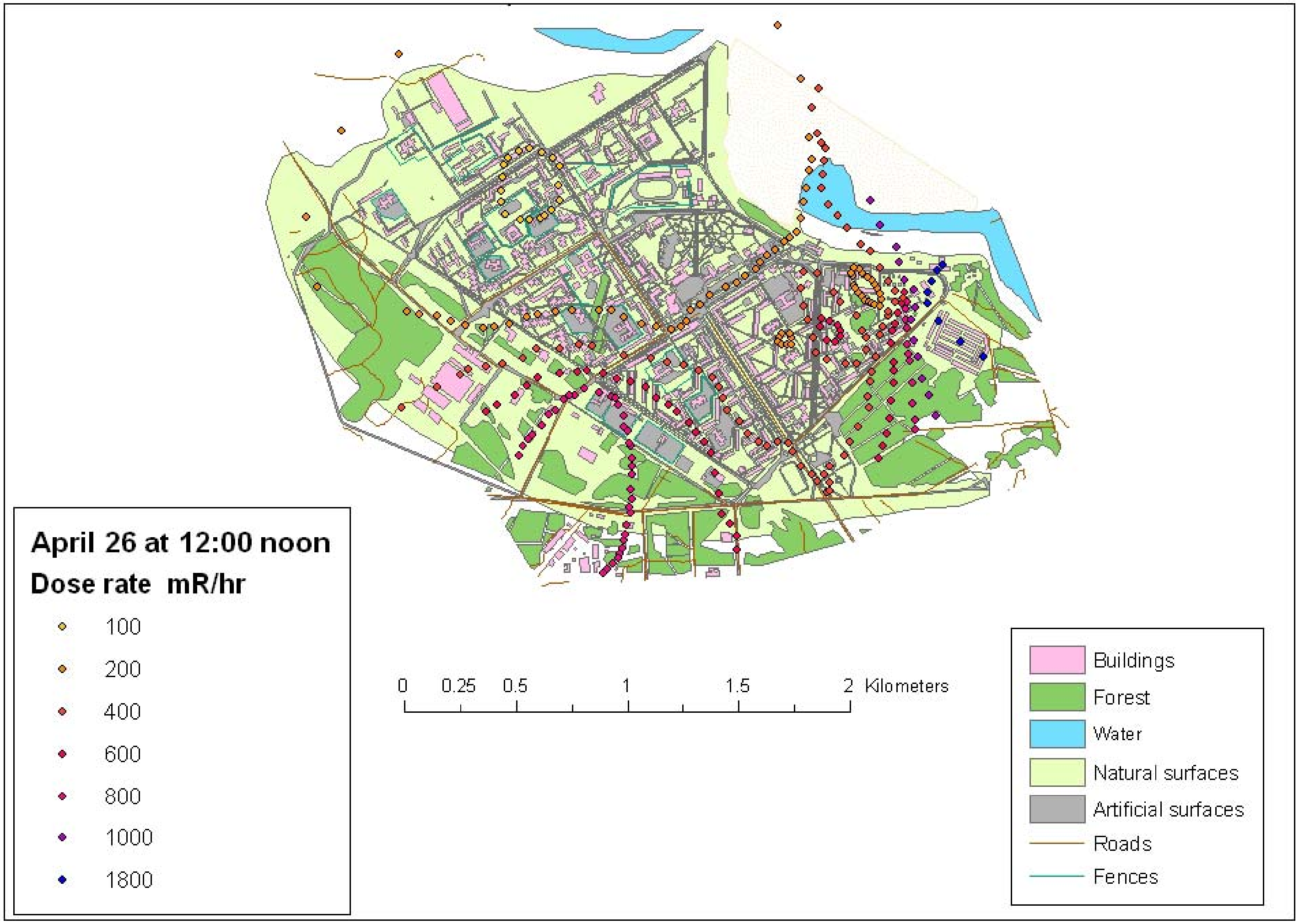


Figure 5. Isolines of dose rate (mR/h) in Pripyat at 12:00 (noon) on 26 April 1986 (see also Table 11).

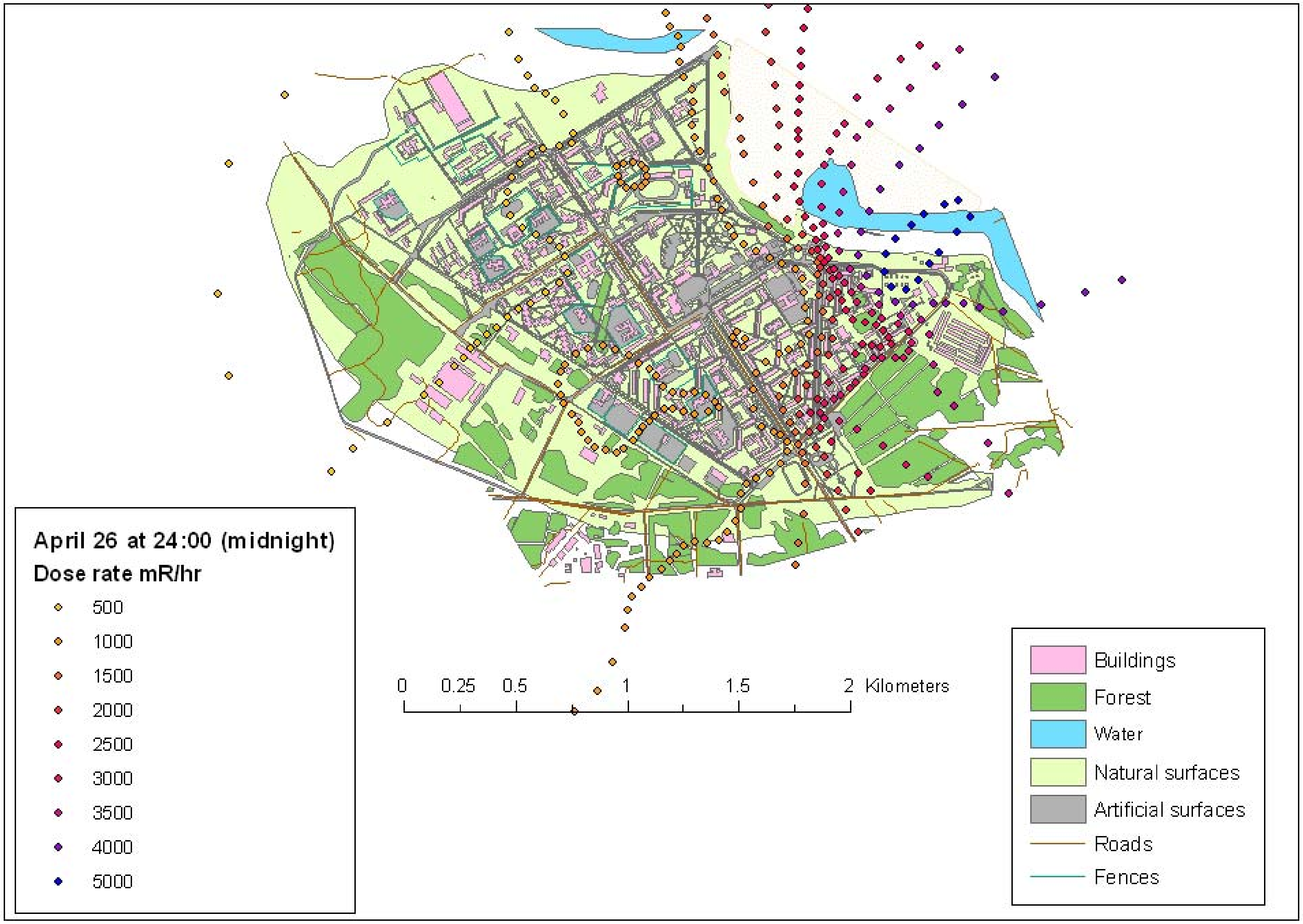


Figure 6. Isolines of dose rate (mR/h) in Pripyat at 24:00 (midnight) on 26 April 1986 (see also Table 12).

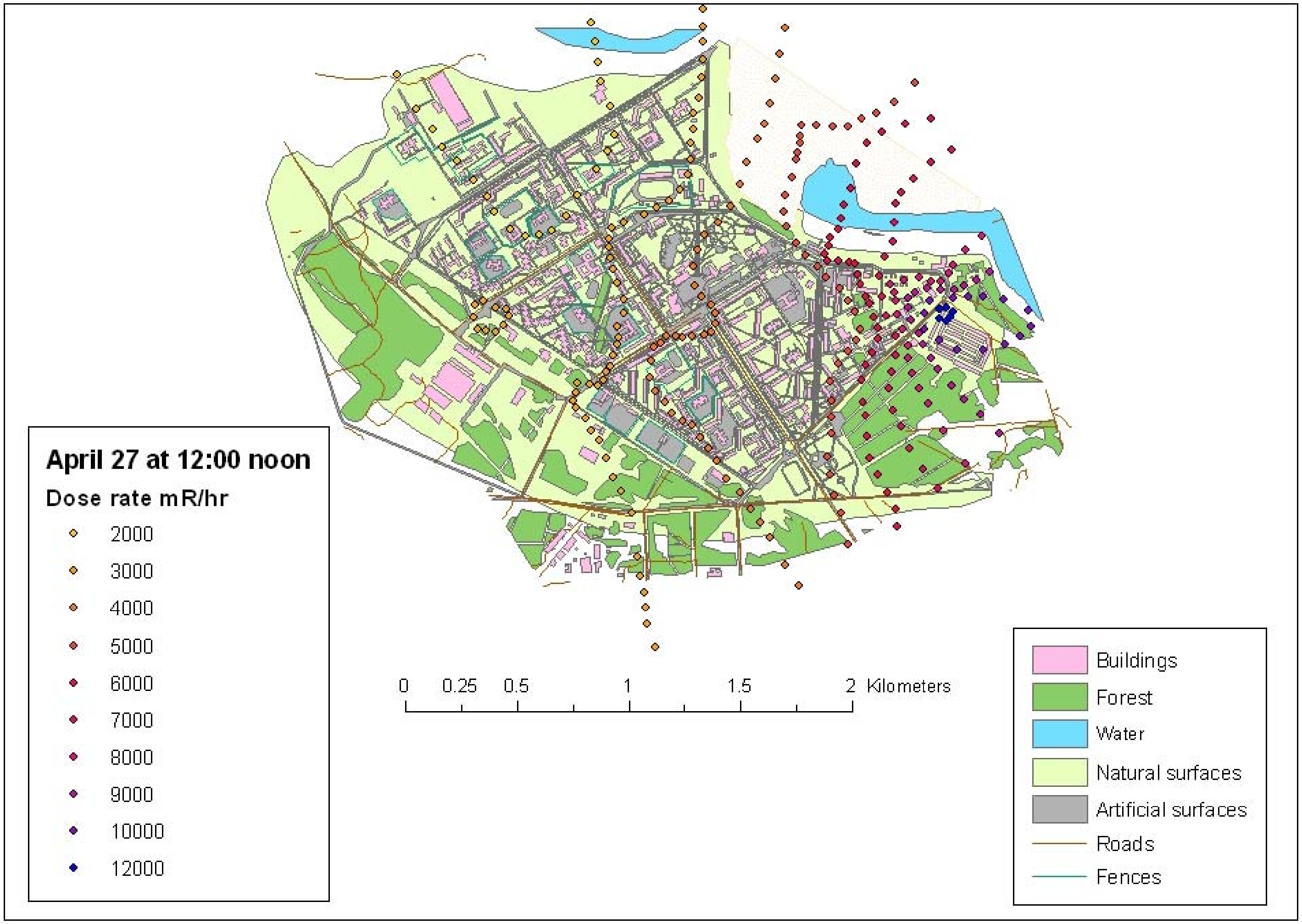


Figure 7. Isolines of dose rate (mR/h) in Pripyat at 12:00 (noon) on 27 April 1986 (see also Table 13).

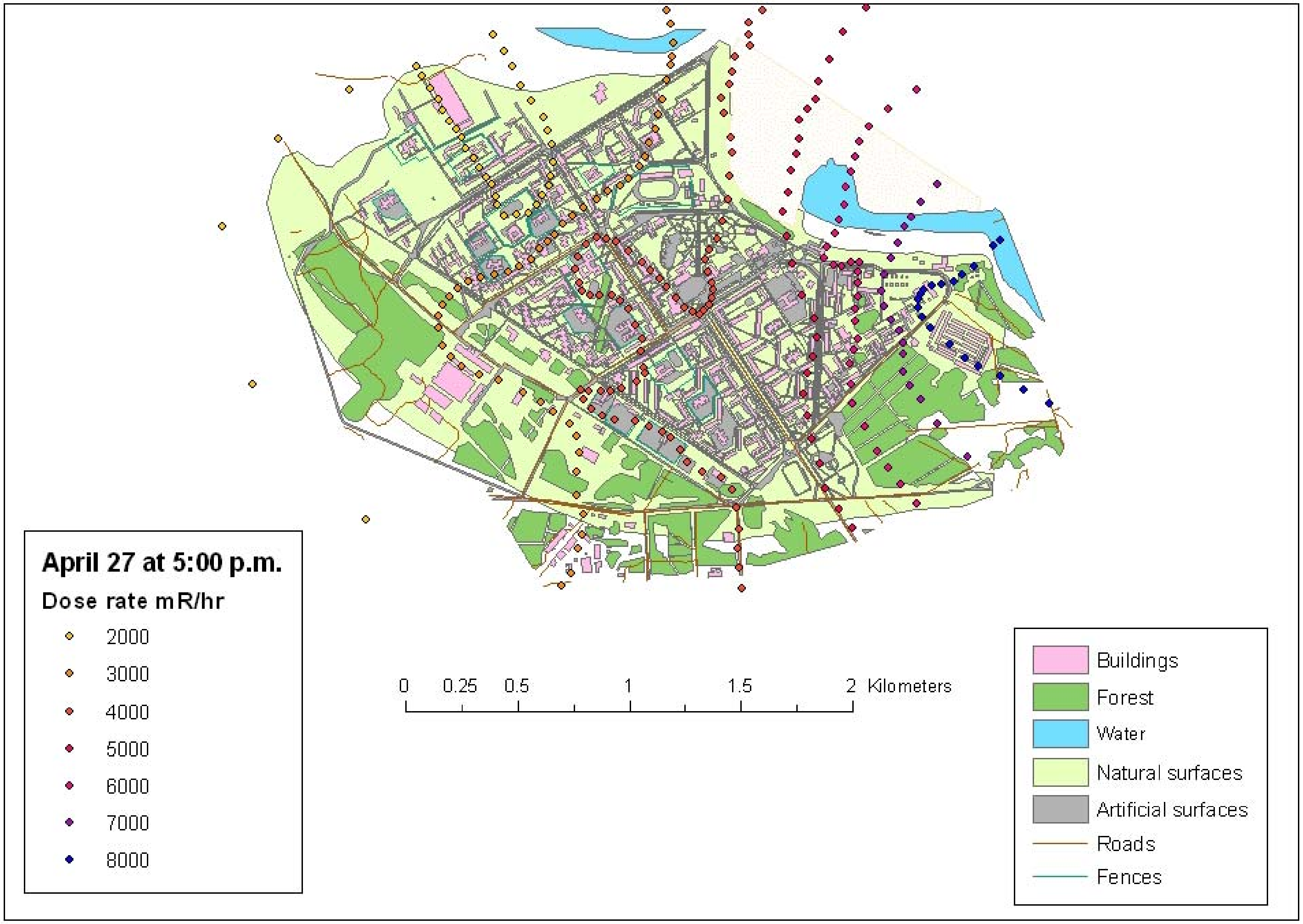


Figure 8. Isolines of dose rate (mR/h) in Pripyat at 17:00 (5:00 p.m.) on 27 April 1986 (see also Table 14).

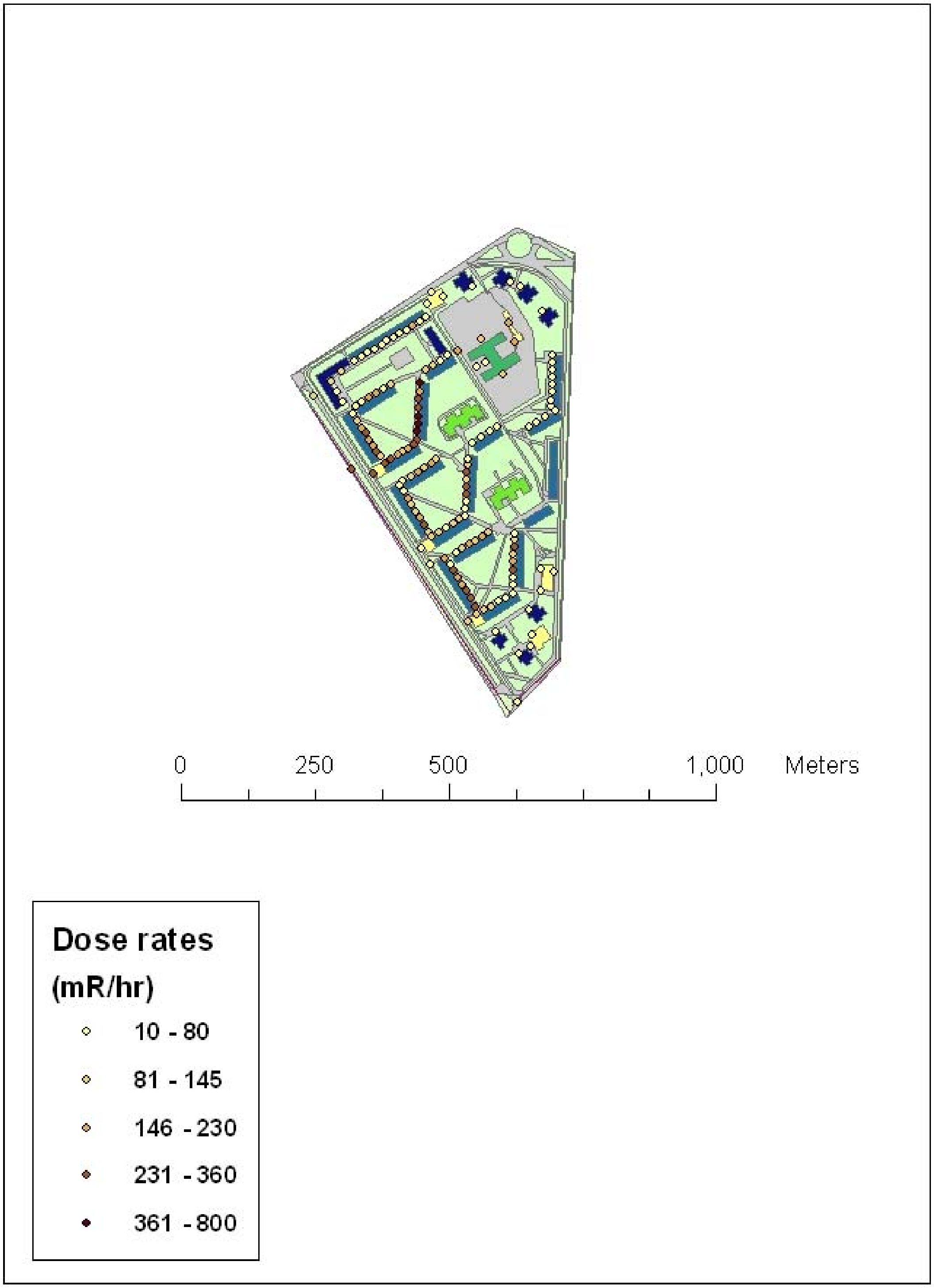


Figure 9. Dose rates (mR/h) measured in District 1 of Pripyat during the summer of 1986. Measured values are given in Table 15.

Fig. 10. Dose rates (mR/h) measured in District 4 of Pripyat during the summer of 1986. Measured values are given in Table 15.

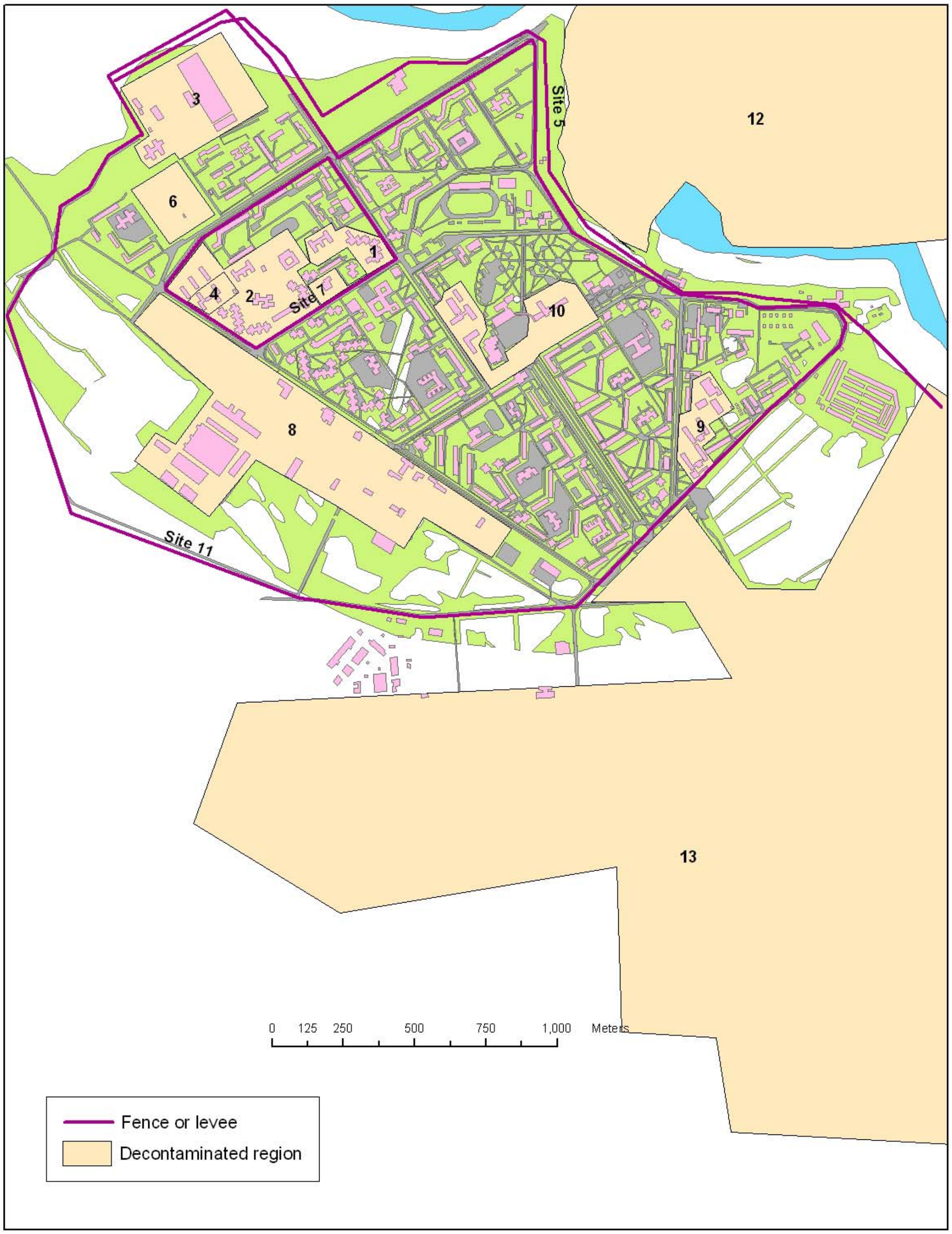


Figure 11. Map of Pripyat showing the sites where major decontamination activities were carried out. For details of the activities in each area, by number, see Table 16 and the main text. Note that sites 5, 7, and 11 correspond to fences or levees, rather than areas.

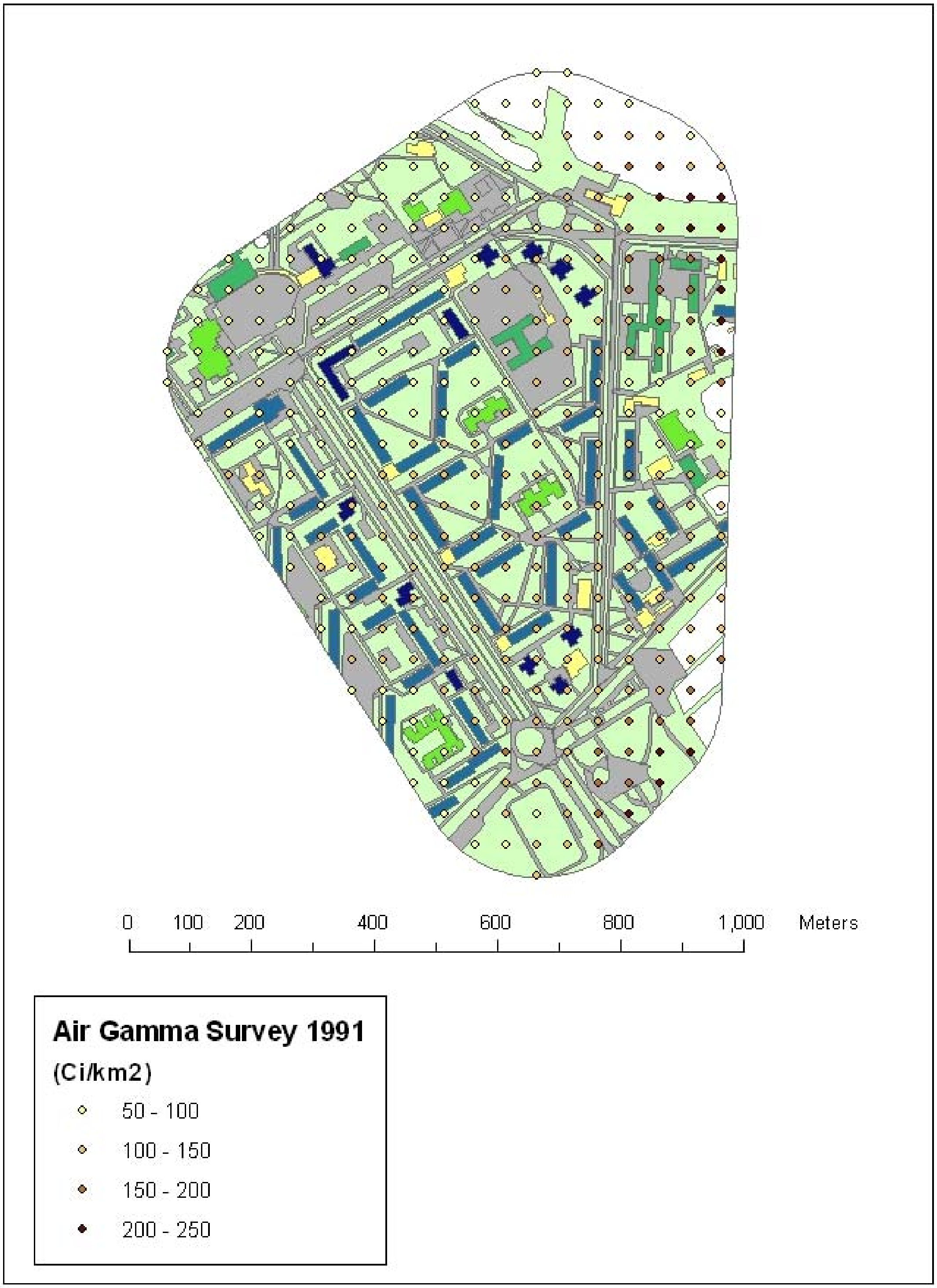


Fig. 12. Results of an air gamma survey performed in 1991, shown for District 1 as calculated values of ^{137}Cs contamination density (Ci/km^2) for a 50 × 50 m grid. Values are provided in Table 21.

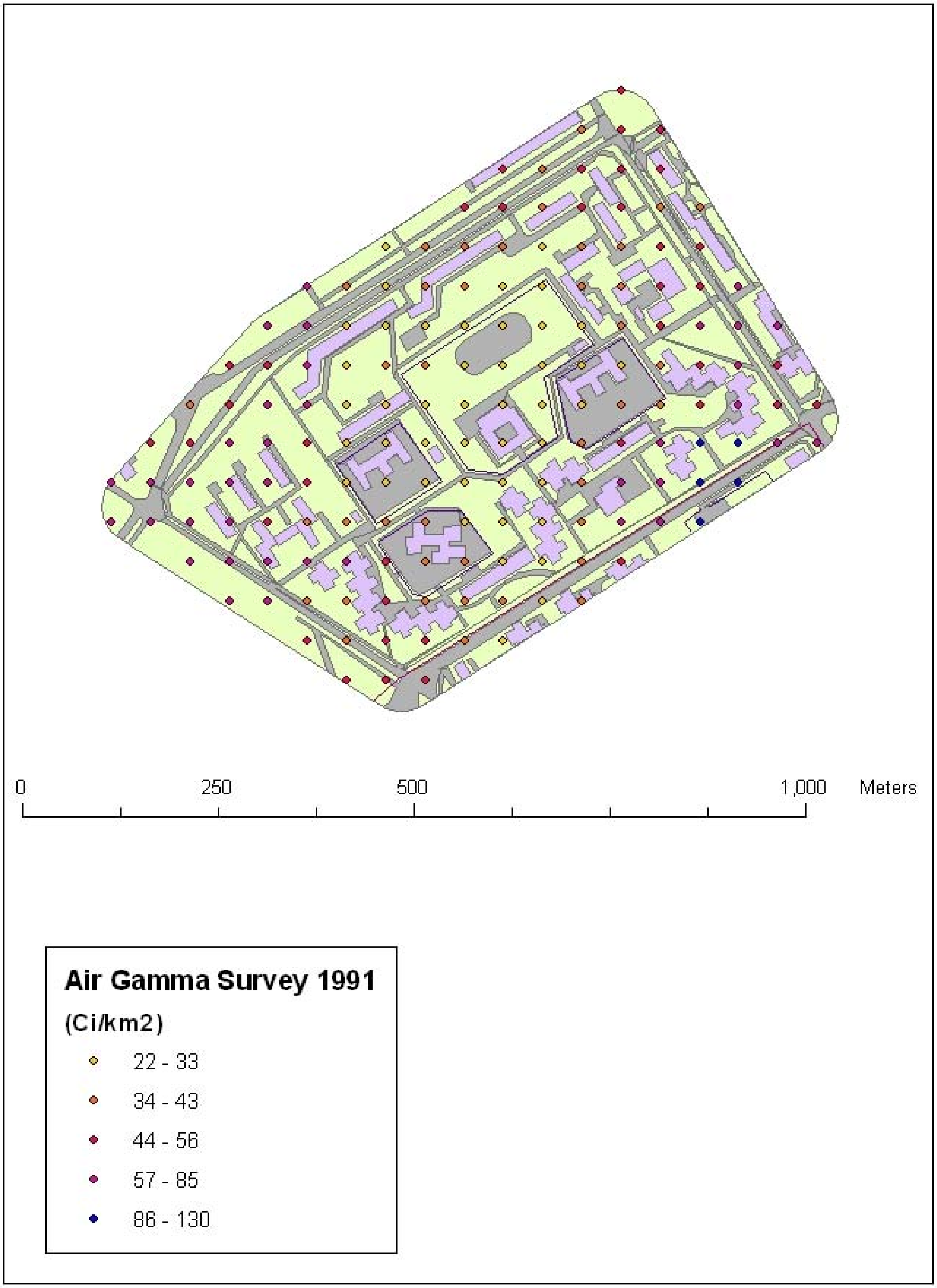


Fig. 13. Results of an air gamma survey performed in 1991, shown for District 4 as calculated values of ^{137}Cs contamination density (Ci/km^2) for a 50 × 50 m grid. Values are provided in Table 21.

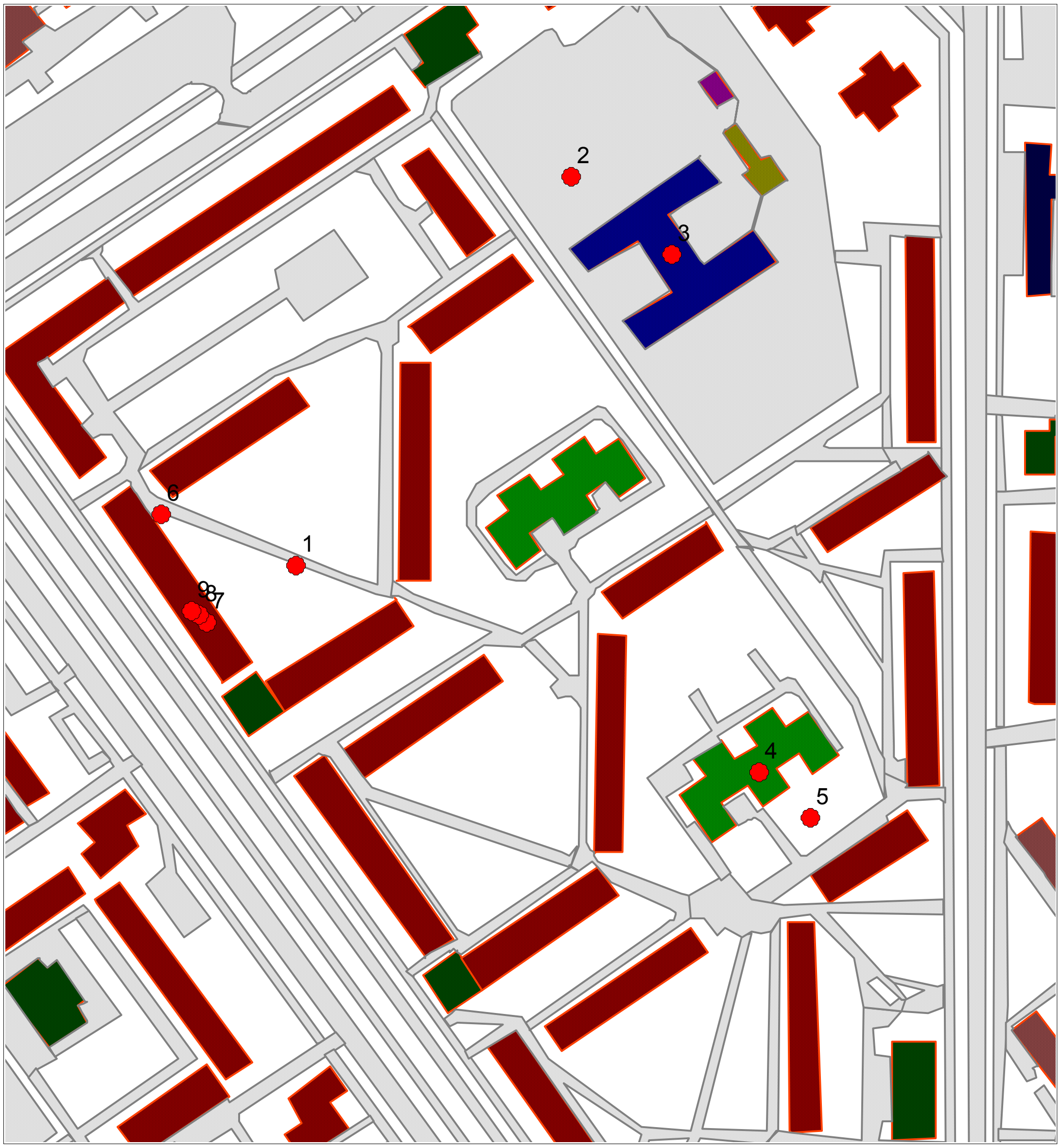


Fig. 14. Locations for model calculations in District #1 of Pripyat. Map positions of the locations are given in Table 23. Locations 1, 2, 5, and 6 are outdoors. Locations 3 and 4 are indoors in schools. Locations 7, 8, and 9 are on the 1st, 3rd, and 5th floors of a 5-story apartment building.

Fig. 15. Locations for model calculations in District #4 of Pripyat. Map positions of the locations are given in Table 23. Locations 13, 14, 15, 20, 21, and 22 are outdoors. Locations 10, 11, and 12 are indoors on the 1st, 5th, and 7th floors of the unfinished end of an apartment building, and locations 17, 18, and 19 are indoors on the 1st, 5th, and 9th floors of a 9-story apartment building. Location 16 is indoors in a 1-floor kitchen. Locations 23 and 24 are on the 1st and 2nd floors of a 2-story kindergarten building.

Appendix

Radiometric survey, October 1986

Summary of the results of a radiometric survey in microdistrict #1a, Pripyat town, 2-3 October 1986. Figure A-1 shows the entire layout of District 1a. The buildings surveyed are at the lower corner of the district, next to the boundary with District 1 (see Figs. 1 and 2), and correspond to buildings #369 (Dormitory #3), #2 (Dormitory #7), #360 (Canteen), #370 (Dormitory #4), and #371 ("Svetlyachok" and an accompanying parking area). Information on the buildings (area, height, locations, etc.) is provided in Table A-1.

The diagrams below (following Fig. A-1) show the locations of sampling points on and between the buildings; the diagrams are not necessarily drawn to scale. The measurements are provided in Table A-2. For gamma radiation, the measurements are reported in mR/h; for beta and alpha radiation, the measurements are in counts per minute. The data in the Excel worksheet (Table A-2) should be correlated with the diagrams as follows:

Column	Title of column	Explanation
A	Layout	This number refers to the number of the diagram below. (The general layout diagram is not included in the numbers.)
B	Location 1	Name of building as indicated in the general layout diagram
C	Location 2	Part of the building (e.g., which wall)
D	Location 3	Additional description of the sampling point (e.g., roof surface or wall surface)
E	Substrate	Type of surface where the sampling was done
F	Height over land, m	Distance above ground level
G	Remoteness from wall, m	Distance of the sampling point from the wall, when relevant
H	Point #	Corresponds to the number of the sampling point from the diagram indicated in column A
I	Alpha, counts	Measurement of alpha radiation (counts per minute)
J	Beta, counts	Measurement of beta radiation (counts per minute)
K	Gamma0, mR/hr	Measurement of gamma radiation near the surface
L	Gamma1, mR/hr	Measurement of gamma radiation at height of 1 m

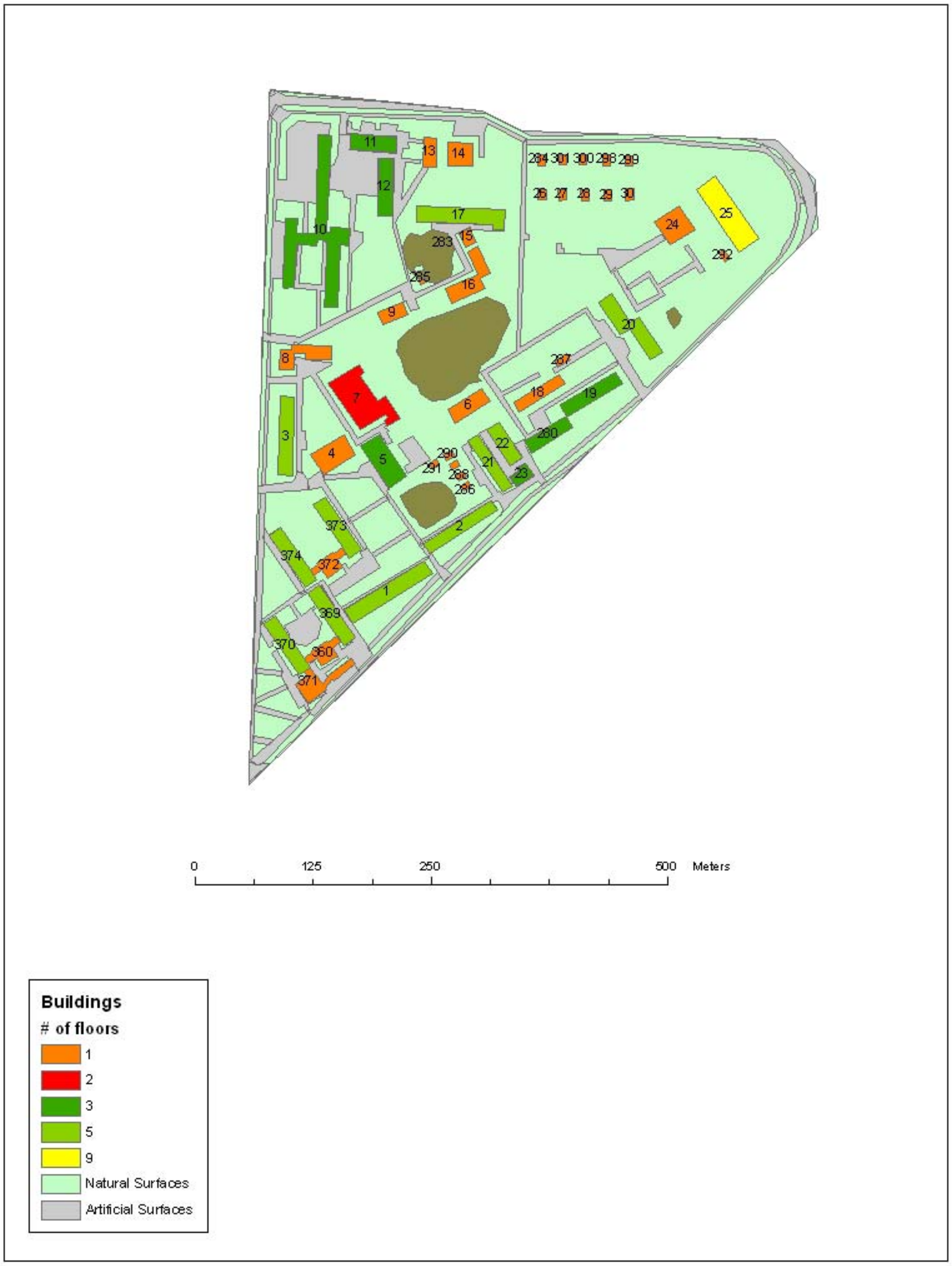
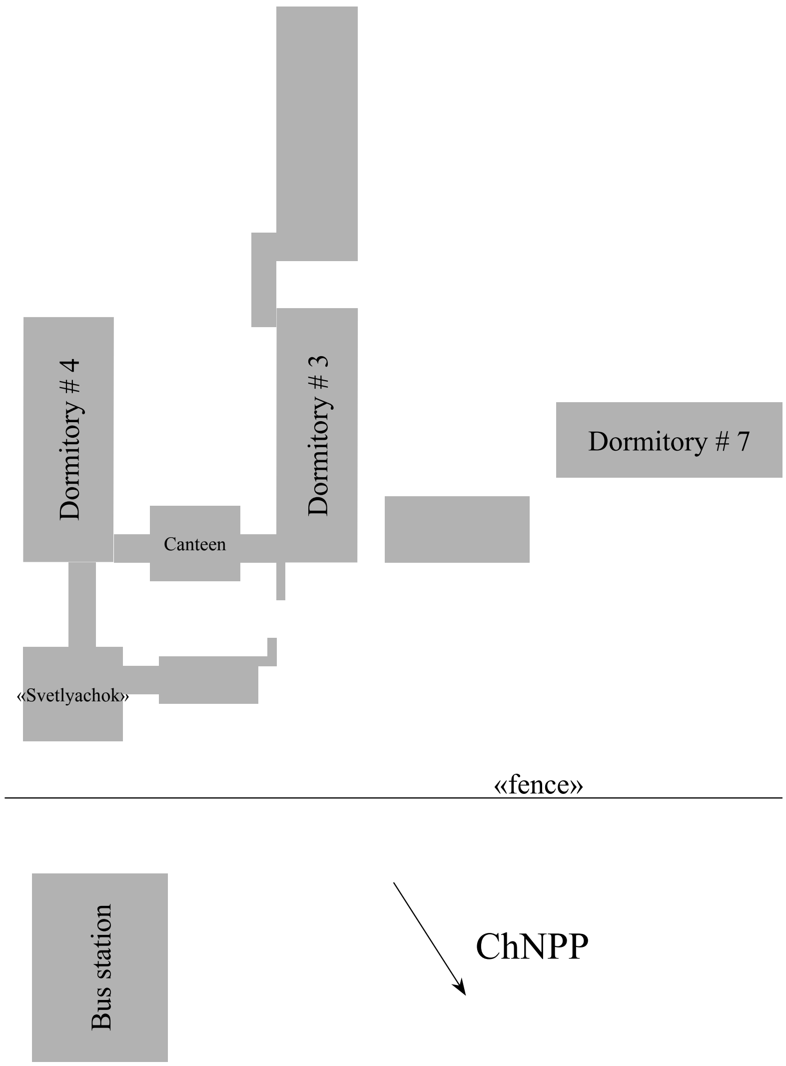
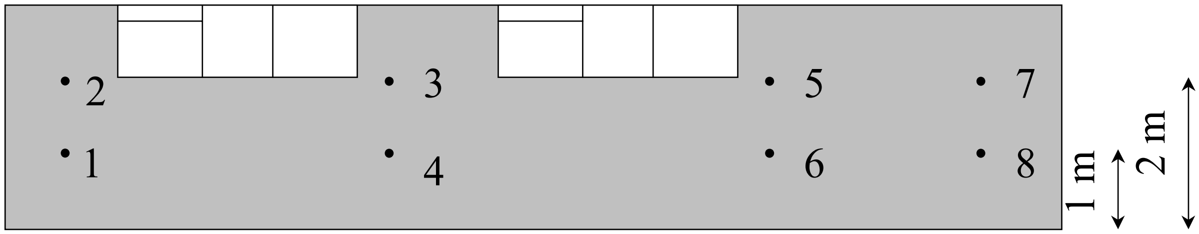


Figure A-1. Map of District 1a of Pripyat, showing building locations and heights. Buildings are listed by number in Table A-1.

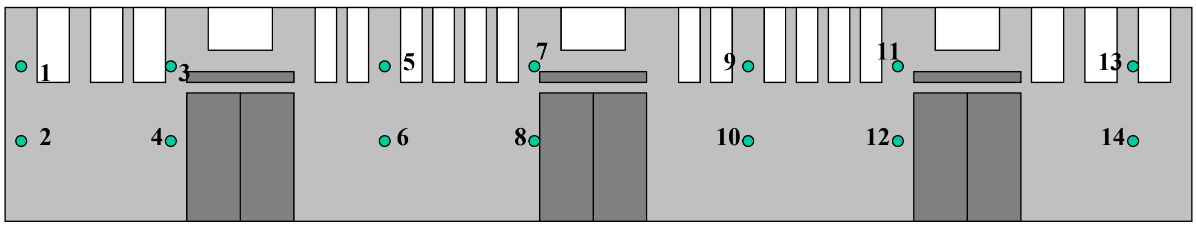
General layout of the Pripyat district, studied



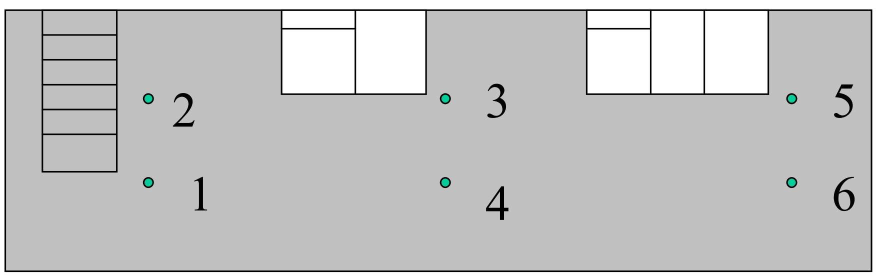
1. Southern wall of dormitory # 3



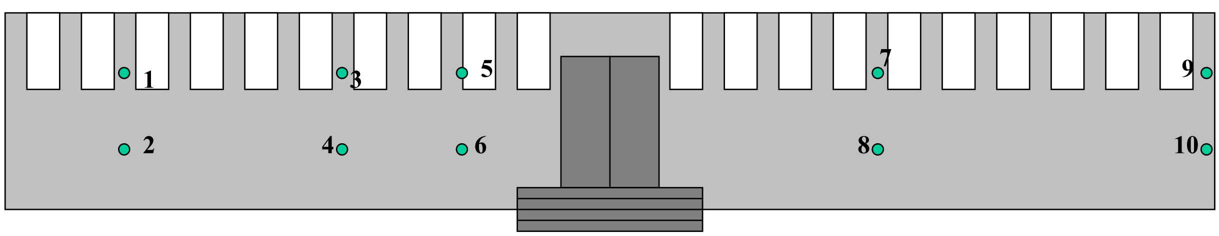
2. Eastern wall of dormitory # 3



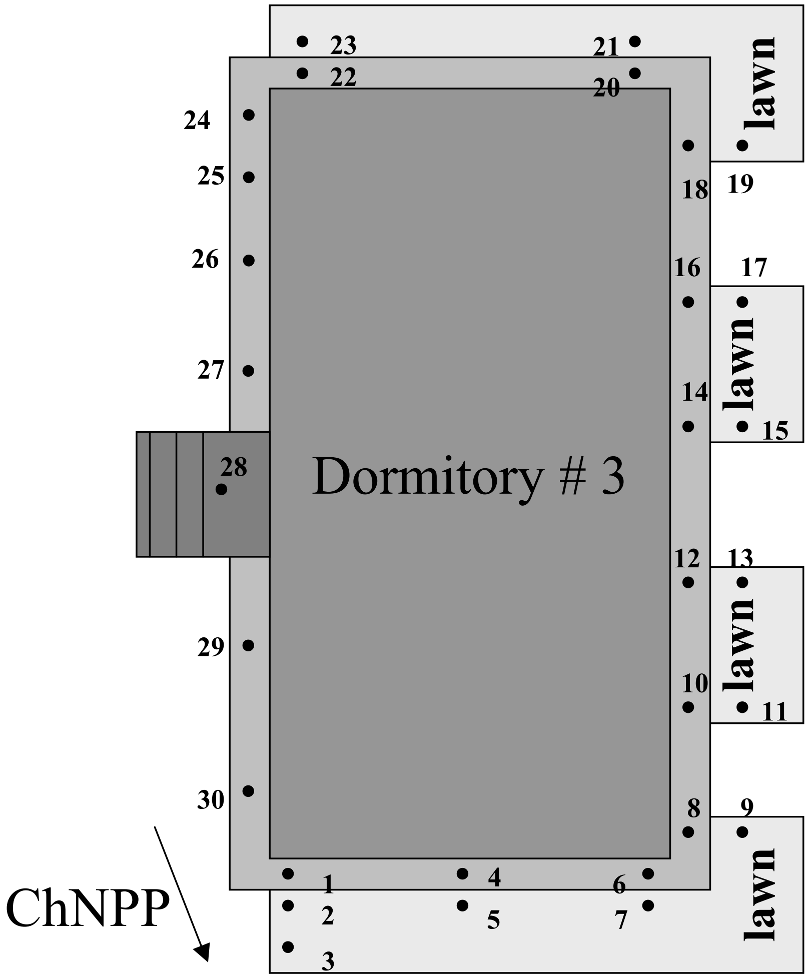
3. Northern wall of dormitory # 3



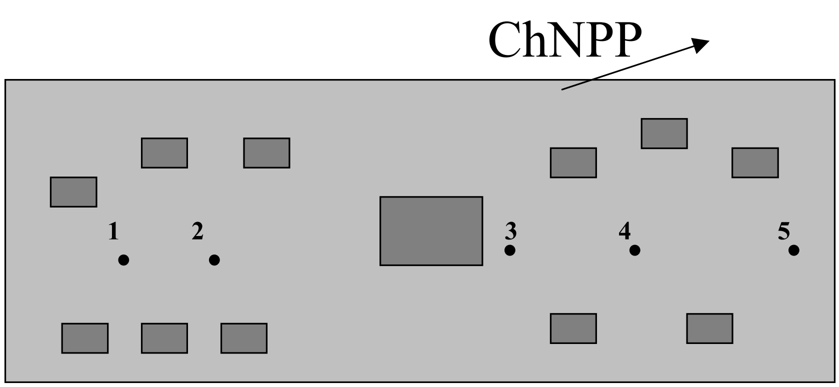
4. Western wall of dormitory # 3



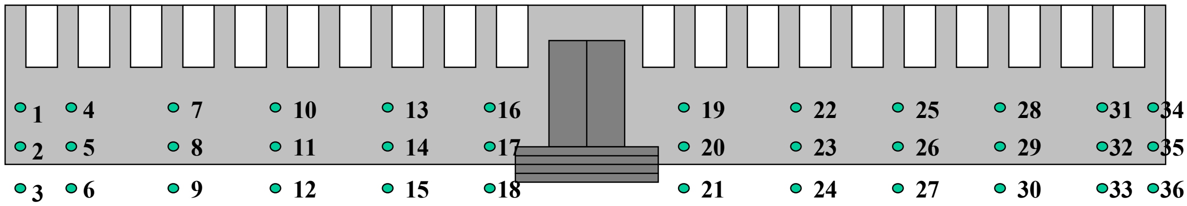
5. Area around dormitory # 3



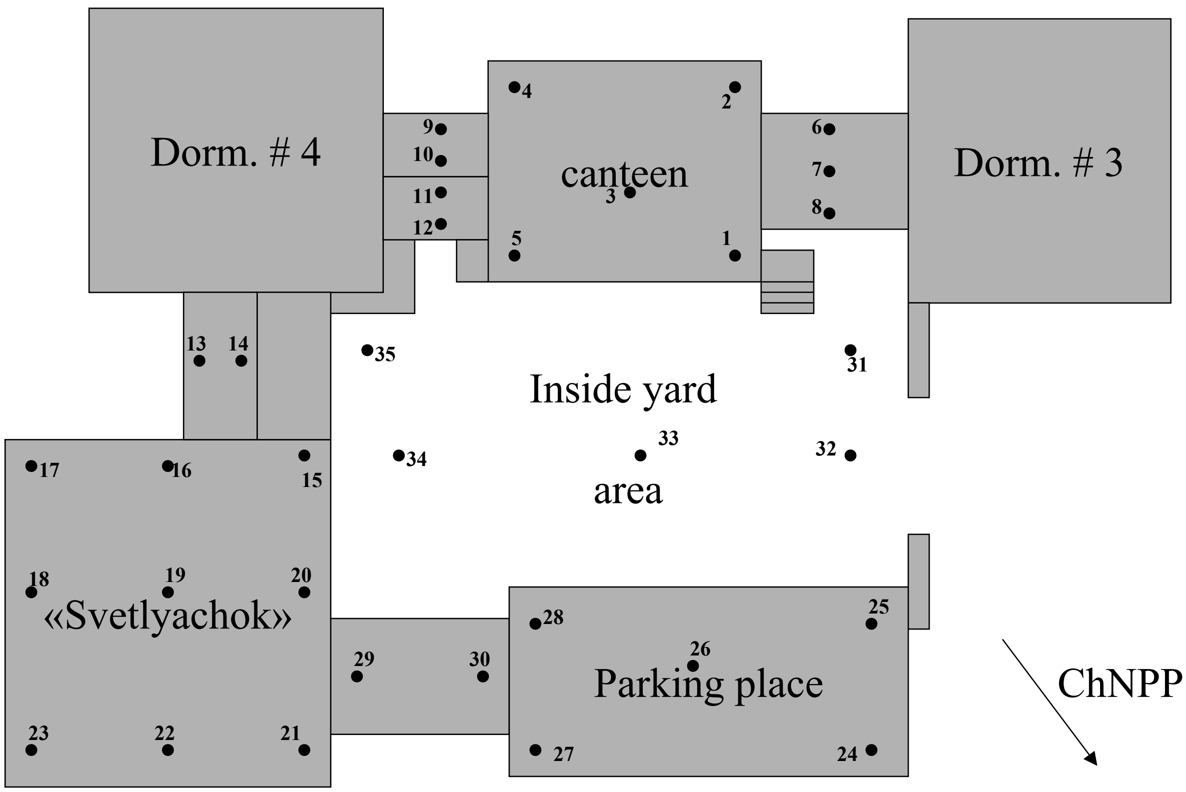
6. Roof of dormitory # 3



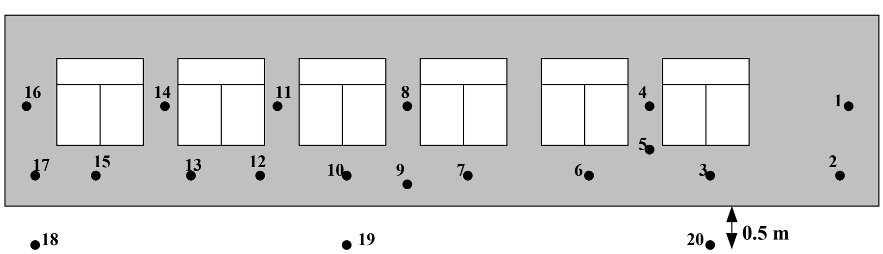
7. Southern wall of dormitory # 7



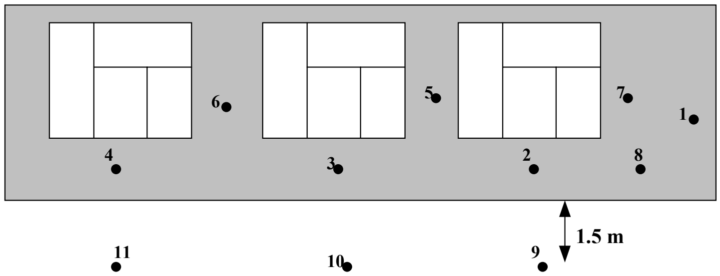
8. Roofs of the canteen and adjoining outbuildings



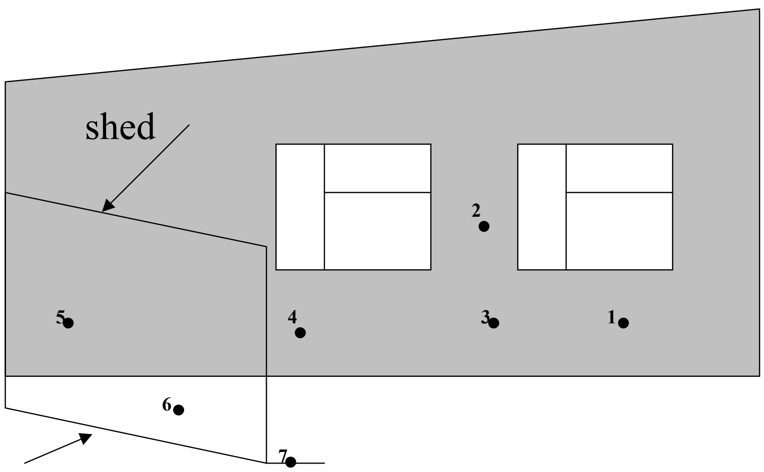
9. Southern wall of canteen



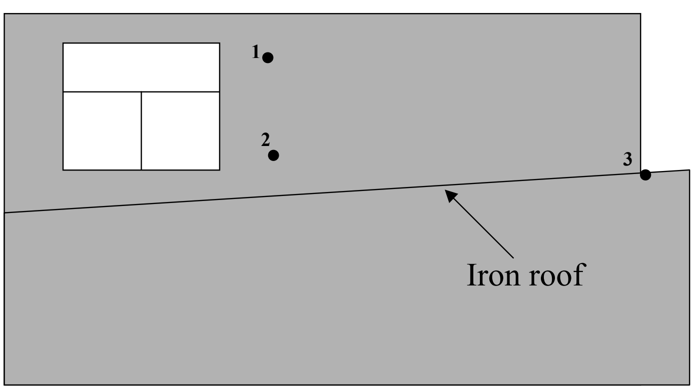
10. Wall of the eastern canteen passage



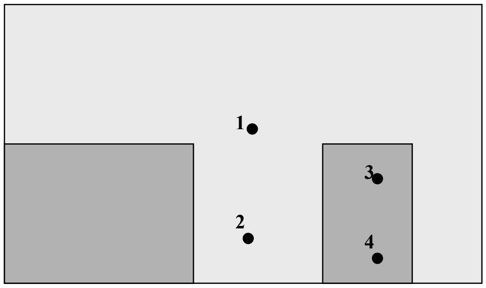
11. Eastern wall of the canteen



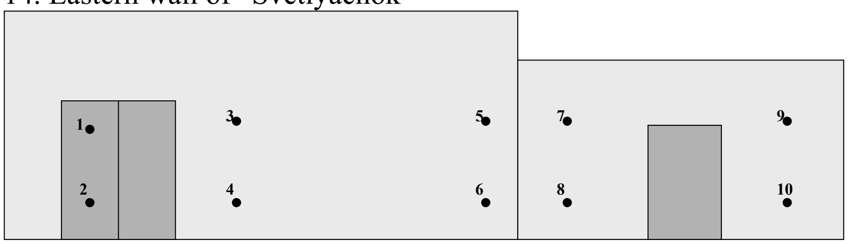
12. Western wall of the canteen



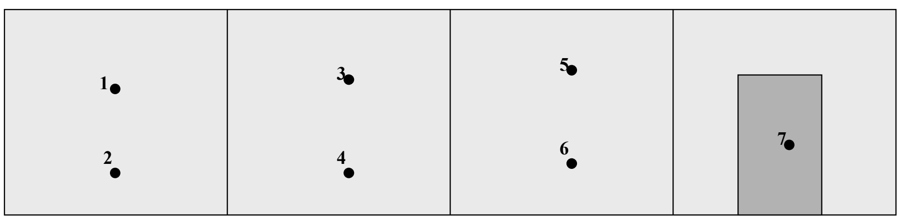
13. Southern wall of the passage



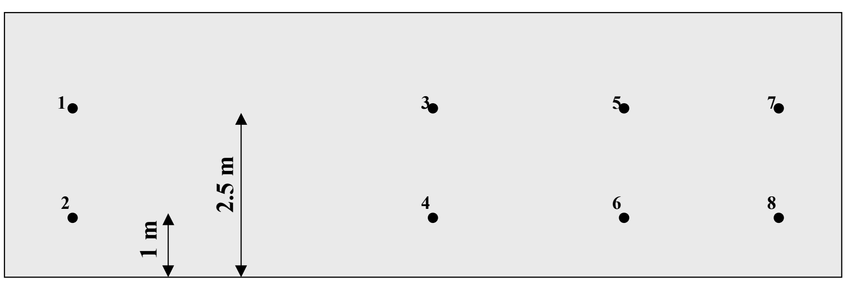
14. Eastern wall of “Svetlyachok”



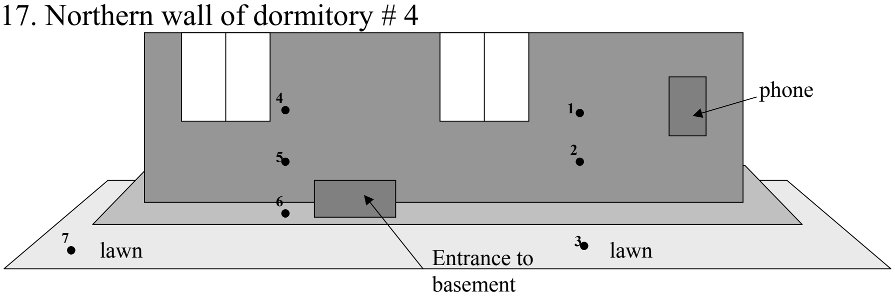
15. Northern wall of the “Svetlyachok’s” outhouse



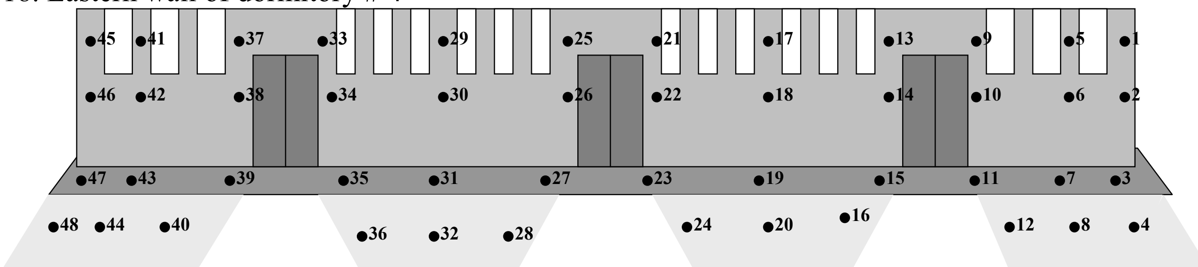
16. Northern wall of parking place



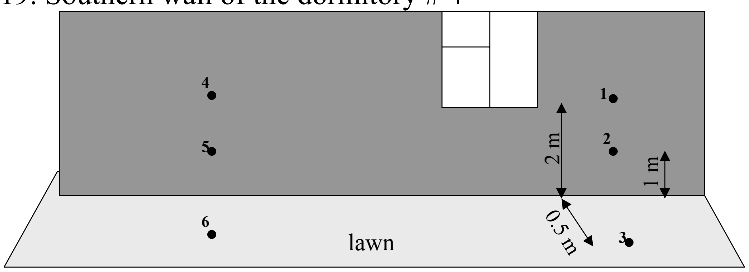
17. Northern wall of dormitory # 4



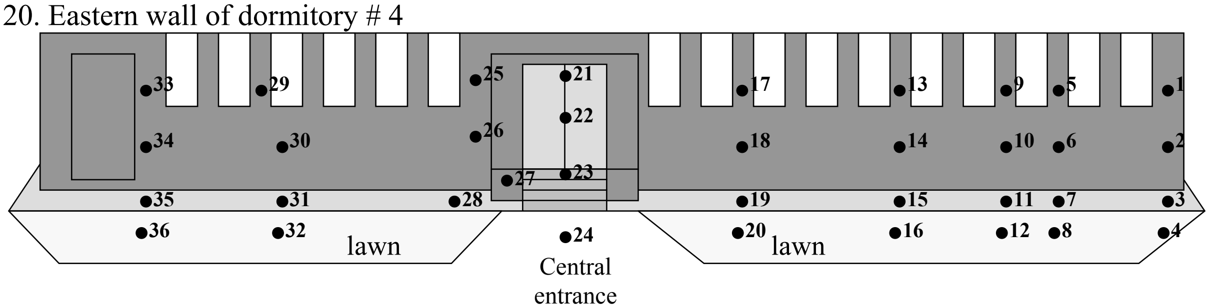
18. Eastern wall of dormitory # 4

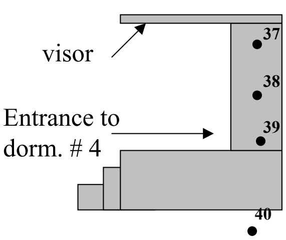


19. Southern wall of the dormitory # 4

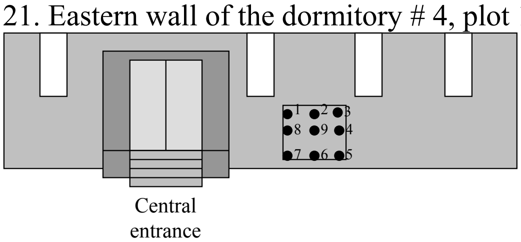


20. Eastern wall of dormitory # 4

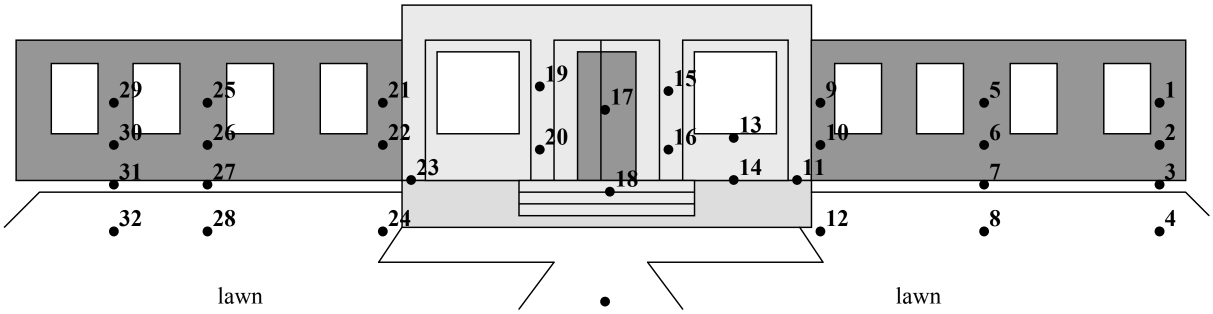




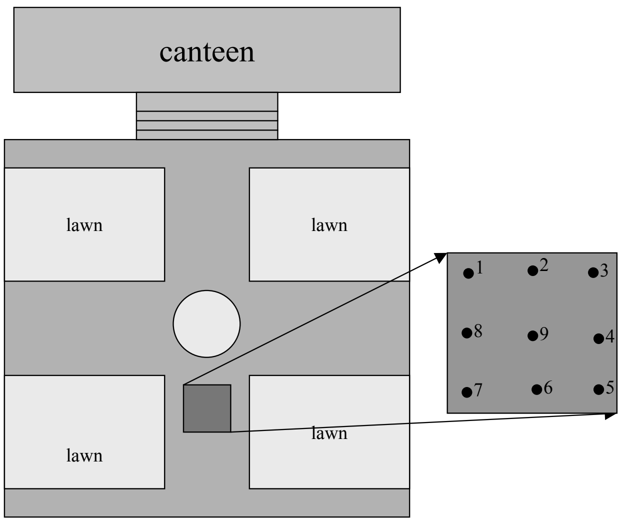
21. Eastern wall of the dormitory # 4, plot 1x1 m



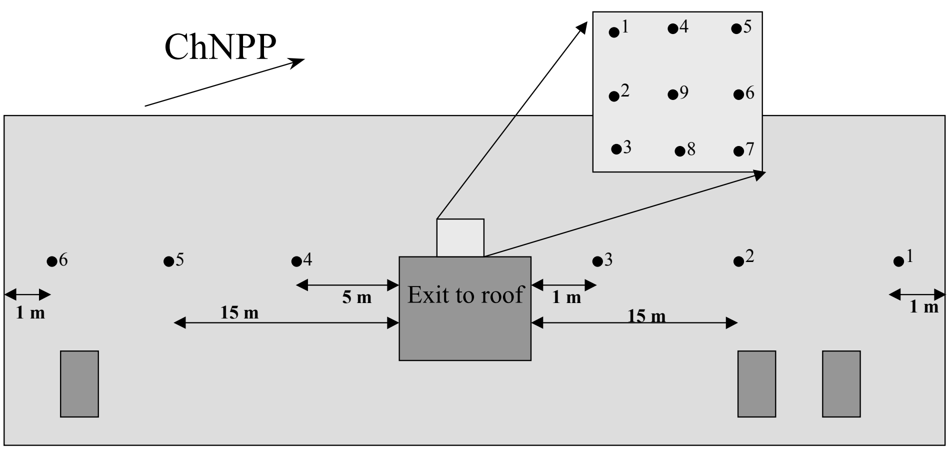
22. Northern wall of the canteen



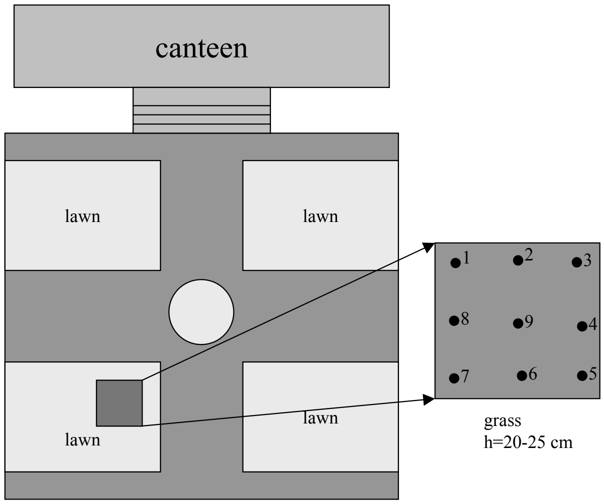
23. Foot-path in the yard between canteen and two dormitories, plot 1x1 m



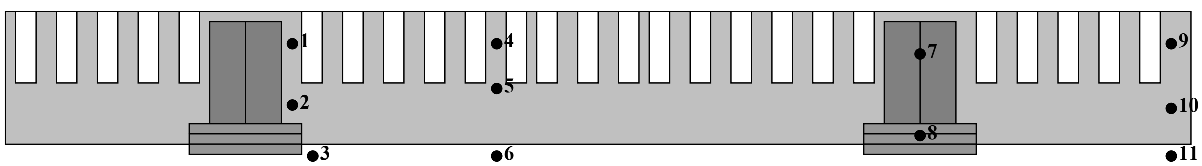
24. Roof of the dormitory # 4, and 1x1 m plot of the roof



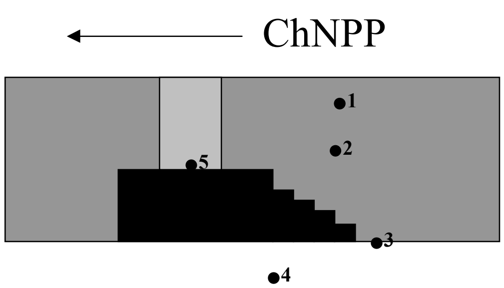
25. Lawn in the yard between canteen and two dormitories, plot 1x1 m



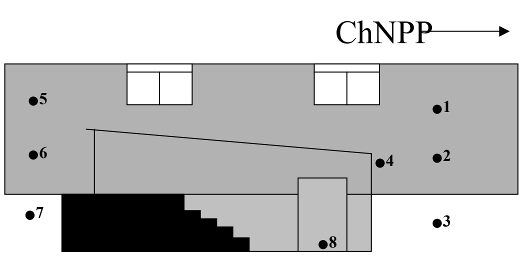
26. Northern wall of the dormitory # 7



27. Eastern wall of the dormitory # 7



28. Western wall of the dormitory # 7



29. Roof of the dormitory # 7