SCENARIO R:
ATMOSPHERIC RESUSPENSION OF RADIONUCLIDES

ABSTRACT

Atmospheric resuspension of radionuclides from contaminated soil can be an important secondary source of contamination after a release has stopped, as well as a source of contamination for people and areas not exposed to the original release. Based on measurements collected after the Chernobyl accident, the "Resuspension" Scenario provides an opportunity to test models for atmospheric resuspension of radionuclides, to investigate resuspension processes on both local and regional scales, and to investigate the importance of seasonal variations of these processes. The scenario includes three different types of situations:

(1) locations within the highly contaminated 30-km zone, where local resuspension processes are expected to dominate;
(2) a large urban location (Kiev) outside the 30-km zone, where vehicular traffic is expected to be the dominant mechanism for resuspension; and
(3) an agricultural area west of the release site, where highly contaminated upwind "hot spots" are expected to be important.

Input information includes characteristics of the ground contamination around specific sites, climatological data for the sites, characteristics of the terrain and topography, and locations of the sampling sites. Available test data include average (quarterly and yearly) concentrations of ^{137}Cs in air at specified locations, concentrations of ^{90}Sr and $^{239+240}Pu$ in air at one location and time point, and specified resuspension factors and rates. A detailed description of each location is provided, along with input information and tables of test data.

INTRODUCTION

The "Resuspension" Scenario (Scenario R) is one of three major test scenarios presented by the Post-Chernobyl Data Working Group of BIOMOVS II (BIOspheric Model Validation Study, Phase II) for testing models at the process level (BIOMOVS II, 1996; Garger et al., 1996; 1999). The "Resuspension" Scenario is based on studies of the resuspension of particulates deposited on the land surface following atmospheric releases of radioactive materials from Unit 4 of the Chernobyl Nuclear Power Plant (NPP) in April 1986. The scenario includes data obtained at several sites in Ukraine, reflecting different levels of contamination and different types of potential exposure situations.

Resuspension is the process by which surface deposits of radioactive particles are re-entrained into the air by mechanisms such as wind action and mechanical disturbances enhanced by human activity. Although generally not considered to be a significant pathway of human exposure during the time that an initial release from a facility is in progress, resuspension may become an important secondary source of airborne exposure after a release has stopped. In addition, it may become a new source of exposure for persons who were not exposed to the original plume but who live downwind of the deposited material. As a result, the resuspension pathway must be included when the long-term effects of radioactive releases to the environment are considered.

In the region of this scenario, resuspension results from the action of wind blowing across the terrain and from mechanical disturbances such as the movement of motor vehicles and the activity of farm equipment. In addition, the data gathered near the Chernobyl site reflect major disturbances such as the demolition of buildings and the burial of the highly radioactive "red" forest. These activities took place prior to 1989. However, enhanced resuspension that may have resulted from major building and forest fires within the 30-km exclusion zone around the Chernobyl site are not evident in these data.

The data in this scenario reflect the heterogeneity of potential exposure to resuspended material. Persons may be exposed to material that is deposited close to where they reside. In addition, the same persons may also be exposed to material initially deposited elsewhere that has been transported to their location by the wind after the material has been resuspended. For example, persons living far downwind of the 30-km zone may be exposed both to radioactive materials resuspended from the 30-km zone and to radioactive materials resuspended from deposition zones located near where they live.

Scenario R provides an opportunity to test models for atmospheric resuspension of radionuclides, to investigate resuspension processes on both local and regional scales, and to investigate the importance of seasonal variations of these processes. This scenario does not provide the extensive information required to study the resuspension process in detail. However, this scenario does provide an excellent opportunity to test models designed to assess the long-term impact of future or past releases of radioactive material.

Input data provided in this scenario include maps, tables characterizing the level of ground contamination around each site, and information on climatological conditions, wind velocity, air temperature, precipitation, dust storm occurrence, and duration of snow cover. Available test data include quarterly and annual average concentrations of ^{137}Cs in air at three locations, concentrations of ^{137}Cs, ^{90}Sr, and $^{239+240}Pu$ in air at one location in Kiev, and resuspension factors and resuspension rates at specified locations and dates. A detailed description of the "Resuspension" Scenario is provided below, followed by tables of input data and test data. Additional information, including the results of the original BIOMOVS II model testing exercise, has been reported by Garger et al. (1996; 1999) and BIOMOVS II (1996).

DESCRIPTION OF THE "RESUSPENSION" SCENARIO

The "Resuspension" Scenario examines three situations in which different levels of inhalation exposure could occur. The first situation involves two locations (Pripyat and Zapolie; Figure 1) within the highly contaminated 30-km zone, where exposures to resuspended material are probably dominated by local processes. A second situation involves the much less contaminated urban area of Kiev (about 110-120 km southeast of Chernobyl), where the local processes dominating the exposure include extensive vehicular traffic. Finally, the third situation involves data for a location 40-60 km west of the Chernobyl reactor (Polesskoe; Figure 1). Exposures at this location are influenced both by resuspension of locally deposited radioactive materials and by the transport of material from upwind sources, for instance, the heavily contaminated 30-km zone, and large, highly radioactive deposits (hot spots) within the district.

Site Descriptions for Pripyat and Zapolie

Conditions within the 30-km Exclusion Zone

A map of the surface contamination of ^{137}Cs within 10 km of the Chernobyl NPP is provided in Figure 2. This map is based on systematic collection and analysis of soil samples within the region during the summer of 1990. The results of soil analyses for selected observation points in the southern half of the 30-km exclusion zone during the summer of 1986 are presented in Table 1. For each site listed in this table, at least three samples 15 cm in diameter were taken to a depth of 5 cm and analyzed for radionuclide content. The results are reported in terms of the density of surface soil contamination, in units of MBq m^{-2}.

Pripyat

Resuspension was studied at a site in the center of the city of Pripyat (asterisk in Figure 2). The surface at this location is sand covered with grass and brush. The surface roughness, z_o, of this urban location is approximately 1 m. This site was influenced by at least two major periods of mechanical resuspension. During the fall of 1987, a number of contaminated homes and other buildings located around the Chernobyl NPP were demolished. A highly contaminated forest downwind of the site was buried in the spring of 1988, and a significant amount of contaminated soil was disturbed (Garger, 1994). Measured concentrations of various radionuclides in Pripyat, Zapolie, and other locations within the 30-km zone, representative of the summer of 1986, were obtained (Table 1; Figure 2). The concentration of ^{137}Cs in the surface soil was measured at 5.22 MBq m^{-2} in Pripyat, and at 0.35 MBq m^{-2} in Zapolie.

Zapolie

A permanent base field site is located in Zapolie, a village approximately 14 km south of the Chernobyl NPP. The Zapolie study area is located on the largest open place (a grass field approximately 1800 m by 600 m in size) within the 30-km exclusion zone. Measurements were started at Zapolie soon after the Chernobyl release stopped. The density of the radionuclide contamination measured at this site in 1986 is given in Table 1. The Zapolie study site was selected on the basis of the quasi-homogeneity of the surface contamination within 200 m of the sampling location at the site. This size is sufficient for the formation of a local surface boundary layer of resuspended radioactive material (Byzova et al., 1989). For 20 soil samples taken at the site, the coefficient of variation was largest for ^{137}Cs (22%) and smallest for ^{106}Ru (10%). This is a relatively high index of homogeneity for the 30-km exclusion zone. The soil characteristics of the Zapolie site are similar to those for the remainder of the 30-km exclusion zone and the Polesskoe region. The surface roughness, z_o, for this grass-covered site is approximately 0.1 m.

Site Description for Kiev

The city of Kiev is located approximately 120 km southeast of the Chernobyl NPP. Kiev, which has approximately 3 million residents, was considerably less contaminated than Pripyat or Zapolie. Vehicular traffic is believed to be the dominant mechanism for the resuspension of contaminants in this region.

Air concentration and ground deposition measurements were made at six locations in Kiev: five in typical urban squares near pedestrian and vehicular traffic and one in an urban park location. The surface roughness, z_o, of the park site is approximately 1 m. Long-term measurements were made at the park site, which is a permanent station; the other five locations were used only for a special study conducted in December 1991. The densities of the ground contamination for the radionuclides ^{137}Cs, ^{90}Sr, and ^{239}Pu + ^{240}Pu were measured at all six locations (Table 2), along with concentrations of these same radionuclides in road dust (Table 3).

Site Description for Polesskoe

The agricultural district and settlement of Polesskoe is located 40-60 km west of the Chernobyl NPP and inhabited by about 14,000 residents. Exposures in this area are influenced both by resuspension of locally deposited radioactive materials and by the advection of material from upwind sources, for instance, the heavily contaminated 30-km zone and several large, highly radioactive deposits (hot spots) within the Polesskoe district in particular (Figure 3). As shown on the map, the settlement of Polesskoe is situated between the western, southern, and northeastern hot spots with contamination densities from 3.7 to 10 × 10^4 Bq m^{-2}. 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. Soddy-podsol is the predominant soil type (93.8%) for the region. The particle size distribution associated with this type of soil is given in Table 4. The differential and integral probability distribution functions of the ^{137}Cs concentration in soil in Polesskoe are provided as representative data for September 1987 (Table 5), along with a contour map of the soil concentrations (Figure 4). Resuspension was measured near the center of the city of Polesskoe.

Climatological Data

The sites considered in this scenario are located on a flat plain covered with mixed forests, fields, and settlements of various sizes. Analysis of historical records indicates that the general climatology of the region is basically uniform in nature. Regional summaries are provided for wind speed (Table 6), wind direction (Table 7), air temperature (Table 8), precipitation (Table 9), and frequency of dust storms (Tables 10 and 11). A dust storm is defined as a wind speed 10 m s^{-1} or greater at a height of 1 m, or a wind speed of 15 m s^{-1} or greater at a height of 10 m. The presence of suspended soil particles during a dust storm results in a visibility of 1 km or less in an open area. Steady snow cover for the region begins 22 December and ends 14 March, on average.

The probability of the wind coming from any given direction is between 8 and 17% over the eight primary compass directions (Table 7). February, March, and April have the highest average wind speeds (Table 6). 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. This speed is significant because it is the threshold speed for resuspension of soil particles via the process of saltation. In March and April, the wind exceeds 15 m s^{-1} at a height of 10 m on 1-2 days per month.

EXPERIMENTAL DETAILS

Air Samplers and Measurements

Air sampling sites for Scenario R were located at Zapolie, Kiev, Polesskoe, and Pripyat. The typical high-volume air sampler, "Typhoon," has a sampling rate of 120,000 m^3 d^{-1} (approximately 1.4 m^3 s^{-1}). Air concentrations for such samplers are assumed to be representative at a height of 1.5 m. In addition, other types of air samplers were used at the Zapolie site. One of these consisted of a 15-m mast with gauze cones and cup anemometers at 7 different levels: 0.5 m, 1.0 m, 2.0 m, 4.0 m, 7.0 m, 10.0 m, and 15.0 m (Garger et al., 1990). Another sampler consisted of a gradient installation with four high-volume air samplers (flow = 400 m^3 h^{-1}) set at different heights (1.0 m, 1.9 m, 2.5 m, and 3.5 m). These air samplers were used to measure the vertical profiles of air concentration and to calculate the resuspension rate (Garger et al., 1990; Garger, 1994).

All high-volume air sampler measurements were made on a daily basis. Gamma spectrometry measurements were also performed daily for the air samples collected in Pripyat. For each of the other sites in Scenario R, the air sample filters for a month were assembled and ashed individually; the ashed samples for the entire month were collectively subjected to gamma spectrometry analysis. The cone air samplers were analyzed infrequently as part of a special program. All gamma spectrometer measurements were made with a pure germanium detector (Garger et al., 1990).

Resuspension Rate and Resuspension Factor

Vertical profile air concentration data were used with a semi-empirical diffusion model for surface releases to estimate the resuspension rate for the Zapolie site (Garger et al., 1990; Garger, 1994). This calculation assumed that all of the radioactive aerosol measured was due to local wind resuspension processes and that no significant amount of material was transported to the site from other contaminated locations by wind. The resuspension factor (m^{-1}) was calculated as the ratio of the volume concentration (Bq m^{-3}) of the radioactive materials at a height of 1 m to the amount of contaminant per m^2 of contaminated soil (Bq m^{-2}).

Soil Sampling

In 1986 and 1987, circular soil samples 15 cm in diameter were taken to a depth of 5 cm. Each measurement consisted of 5 such samples taken within 20 m of the location of the air sampling station. After 1987, the soil samples were taken to a depth of 20 cm. Samples taken at Zapolie were analyzed for ^{137}Cs. In Kiev, air and soil samples were analyzed for ^{137}Cs, ^{90}Sr, and $^{239+240}Pu$. Soil samples were collected in Polesskoe in 1987 to define the extent of contamination in the region. If the selected sample square was on tilled soil, i.e., vegetable garden or field, from 3 to 5 samples up to 20 cm in depth were collected. These samples were dried, aggregated, and analyzed by gamma spectrometry.

TEST DATA AVAILABLE

1. Monthly (January, April, July, and October) and annual average concentrations of ^{137}Cs in air (Bq m^{-3}) in Pripyat, Zapolie, and Kiev, from 1987 to 1992 (Tables 12-13).
2. Average concentrations of ^{137}Cs, ^{90}Sr, and $^{239+240}Pu$ in air (Bq m^{-3}) in Kiev in December 1991 (Table 14).
3. Resuspension factors (m^{-1}) for ^{137}Cs, ^{90}Sr, and $^{239+240}Pu$ in Kiev in December 1991 (Table 14).
4. Annual average resuspension rates (s^{-1}) and resuspension factors (m^{-1}) for ^{137}Cs in Zapolie in 1986 and 1992 (Table 15).
5. Annual average resuspension factors (m^{-1}) for ^{137}Cs in the town of Chernobyl in 1986 (May 20-December 31) and 1987-1991 (Table 16).
6. Resuspension factors (m^{-1}) in the 30-km zone in September 1986 (^{137}Cs, ^{106}Ru, ^{144}Ce, and ^{95}Zr) and September 1991 (^{137}Cs) (Table 17).

Discussion of measured concentrations of ^{137}Cs in air

The annual average air concentrations of ^{137}Cs (Bq m^{-3}) at Pripyat, Kiev, and Polesskoe (Table 13) are summarized in Table 18 together with values of the standard deviations. The relative level of the standard deviation varied from 200 to 40%, decreasing with time. The character of the time course of the annual average air concentrations measured at the three sites is shown in Figure 5. In general, annual air concentrations appear to have leveled off by 1992, with the actual concentrations decreasing with distance from the Chernobyl NPP.

More detailed differential data are also given in Table 18. These data characterize the absolute and relative rates of the change in the annual average air concentrations and also in the ratio between the annual difference and the annual standard deviation determined from the average monthly air concentrations. The absolute rates of decrease at these sites differ by orders of magnitude in the second and third years after the accident (Table 18). It is clear that stabilization began sooner in Kiev. The relative rates of decrease are negative for all years for Pripyat; for Polesskoe, the relative rates are lower on the whole than those for Kiev for the period of observation. The third part of Table 18 shows the ratio between the annual difference and the standard deviation; the fluctuating nature of the local resuspension process in Kiev, a large city, is greater than in Pripyat and Polesskoe by factors of 6 and 3, respectively. This is understandable in that Pripyat became a closed and dying city, while Polesskoe was primarily an agricultural area.

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TABLES OF INPUT DATA

Table 1. Density of soil contamination within the 30-km exclusion zone, measured in the summer of 1986 (10^4 Bq m^{-2}).

Place	Distance from source (km)	^{144}Ce	^{141}Ce	^{103}Ru	^{106}Ru	^{137}Cs	^{134}Cs	^{95}Zr	^{95}Nb
Pripyat	4	5550	440	485	1443	522	196	2870	5370
Kopachi	4	1740	148	222	440	163	70.3	866	1260
Lelev	10	481	48.1	75.8	170	70.3	32.9	261	385
Zapolie (village)	14	278	24.0	44.4	115	34.8	19.2	126	200
Zapolie (grass field)	14	688	119	122	-	52.9	23.3	334	577
Zalecie	16	300	28.1	42.6	88.8	35.2	16.3	15.5	223
Korogod	14	45.1	4.80	7.03	17.4	51.8	19.6	22.6	33.7
Opachichi	25	166	15.9	26.3	55.5	19.2	8.88	81.4	126
Yampol	21	207	19.6	40.3	92.5	31.1	11.5	133	192
Zimovitshe	7	7030	966	677	751	238	30.7	-	-
Chernobyl	16	481	40.7	88.8	191	48.1	21.5	237	337
Novoselki	20	197	-	59.2	2.22	25.2	9.25	163	-

Table 2. Density of soil contamination in the city of Kiev, measured in 1991 (10^4 Bq m^{-2}).

Sample location	^{137}Cs	^{90}Sr	^{239}Pu and ^{240}Pu
1	4.3	0.67	0.03
2	3.6	1.00	0.033
3	1.7	0.41	0.01
4	1.6	0.12	<0.001
5	2.8	0.79	0.014
6	1.1	0.5	0.005
Average	2.5	0.58	0.016

Table 3. Concentrations of radionuclides in samples of road dust in the city of Kiev, measured in December 1991 (Bq kg^{-1}).

Sample location	^{137}Cs	^{90}Sr	^{239}Pu and ^{240}Pu
1	7.20	1.8	0.03
2	25.1	4.8	0.13
3	13.1	3.0	0.03
4	19.8	2.5	0.03
5	14.9	4.4	0.07
6	29.7	8.1	0.10
Average	18.3	4.1	0.06

Table 4. Particle size distribution of soil (soddy-podsol) from the Polesskoe district.

Particle size (μm)	Percentage by weight of soil probe
<1	0.10
1 – 5	1.35
5 – 10	1.42
10 – 20	7.35
20 – 30	8.42
30 – 40	11.46
40 – 50	14.52
50 - 100	55.50

Table 5. Differential and integral empirical distribution functions of the density of ^{137}Cs contamination (10^4 Bq m^{-2}) for the settlement of Polesskoe, 1987.

Range of density 10^4 Bq m^{-2}	Probability	Cumulative probability
< 18	0.171	0.171
18-37	0.119	0.290
37-56	0.105	0.395
56-74	0.071	0.466
74-92	0.105	0.571
92-111	0.119	0.690
111-130	0.057	0.747
130-148	0.081	0.828
148-166	0.048	0.876
166-185	0.024	0.900
185-204	0.043	0.943
204-222	0.014	0.957
222-240	0.010	0.967
> 240	0.033	1.000

Table 6. Probability of wind speed at different hours of the day (%).

Month	Time	Intervals of wind speed, m s^{-1}					
	h	0 - 1	2 - 5	6 - 9	10 -13	14 - 17	18 - 20
January	1:00	18.9	53.4	23.0	3.6	1.1	-
	7:00	16.7	55.6	23.1	3.4	1.1	0.1
	13:00	14.4	53.5	27.5	3.8	0.7	0.1
	19:00	18.0	52.3	25.4	3.8	0.5	-
February	1:00	17.6	47.0	29.2	4.2	1.7	0.3
	7:00	16.5	48.8	28.2	5.4	1.0	0.1
	13:00	12.3	45.4	33.2	7.4	1.3	0.4
	19:00	17.4	47.1	28.0	5.1	2.1	0.3
March	1:00	23.0	50.2	21.0	4.6	1.1	0.1
	7:00	15.5	54.9	25.0	3.7	0.8	0.1
	13:00	9.2	48.0	33.8	7.5	1.4	0.1
	19:00	20.1	54.0	20.6	3.9	1.3	0.1
April	1:00	25.7	54.2	16.4	2.6	1.0	0.1
	7:00	18.5	57.8	19.7	2.9	1.1	-
	13:00	7.5	46.2	35.3	8.3	2.6	0.1
	19:00	17.0	60.8	18.4	2.9	0.8	0.1
May	1:00	30.9	54.1	13.3	1.4	0.3	-
	7:00	22.9	57.0	17.4	2.3	0.3	0.1
	13:00	7.8	50.7	34.1	6.1	1.3	-
	19:00	21.8	58.4	17.3	2.2	0.3	-
June	1:00	34.8	56.7	7.2	1.2	0.1	-
	7:00	25.5	62.8	11.2	0.5	-	-
	13:00	9.0	59.5	27.6	3.2	0.4	0.3
	19:00	22.2	62.7	13.4	1.6	0.1	-

Table 6 (continued)

Month	Time h	Intervals of wind speed, m s^{-1} 0 - 1	2 - 5	6 - 9	10 - 13	14 - 17	18 - 20
July	1:00	40.2	53.8	5.6	0.3	0.1	-
	7:00	27.0	63.1	9.1	0.7	0.1	-
	13:00	9.5	60.0	27.7	2.4	0.4	-
	19:00	27.0	60.3	12.0	0.7	-	-
August	1:00	37.9	54.4	6.9	0.7	0.1	-
	7:00	25.3	65.4	9.1	0.1	0.1	-
	13:00	11.8	57.7	28.0	2.0	0.4	0.1
	19:00	28.8	61.9	8.5	0.5	0.3	-
September	1:00	30.1	59.5	8.5	1.2	0.6	0.1
	7:00	23.5	65.5	10.0	0.6	0.3	0.1
	13:00	9.9	51.4	33.3	4.5	0.9	-
	19:00	28.2	61.7	8.6	1.2	0.3	-
October	1:00	26.6	57.5	13.0	1.8	1.1	-
	7:00	21.7	59.8	15.7	2.5	0.3	-
	13:00	9.4	50.0	33.7	5.9	1.0	-
	19:00	24.7	58.9	13.5	2.5	0.4	-
November	1:00	22.6	53.2	20.3	3.5	0.4	-
	7:00	18.4	56.0	22.3	2.6	0.7	-
	13:00	10.4	52.9	32.0	4.0	0.7	-
	19:00	20.9	52.4	23.8	2.2	0.7	-
December	1:00	17.8	51.0	25.4	4.2	1.5	0.1
	7:00	16.2	53.0	25.5	4.2	1.1	-
	13:00	12.9	51.6	30.6	4.0	0.8	0.1
	19:00	15.2	54.9	25.2	3.8	0.6	0.3
year	1:00	27.1	53.9	15.7	2.4	0.8	0.1
	7:00	20.5	58.2	18.2	2.4	0.6	0.1
	13:00	21.5	57.0	18.3	2.5	0.6	0.1
	19:00	10.6	52.5	31.0	4.9	0.9	0.1

Table 7. Probability (%) of wind (by direction) and calm for 1975-1985.

Month	N	NE	E	SE	S	SW	W	NW	calm
1	7.0	5.8	10.1	15.4	10.8	22.1	17.8	10.7	0.3
2	13.5	9.2	19.8	15.1	4.4	10.1	15.8	11.9	0.2
3	7.9	6.0	18.8	24.6	10.2	14.1	11.7	6.3	0.4
4	11.6	13.1	16.2	16.8	7.8	11.5	12.0	10.0	1.0
5	11.3	11.3	20.9	19.0	7.5	8.2	9.7	10.6	1.5
6	15.0	9.4	10.9	11.0	6.6	14.4	15.4	16.1	1.2
7	13.9	9.6	9.4	9.2	4.9	10.7	22.1	18.5	1.7
8	16.7	11.4	13.4	8.7	4.8	12.5	14.6	15.1	2.8
9	9.2	5.9	9.4	16.4	6.0	15.7	20.8	15.0	1.6
10	7.7	4.0	8.7	17.3	10.0	16.9	19.7	13.2	2.5
11	6.7	5.4	8.2	19.1	10.8	21.2	20.8	7.2	0.6
12	7.4	5.8	7.3	21.0	10.7	19.9	19.0	8.7	0.2
year	10.6	8.1	12.7	16.2	7.9	14.8	16.6	11.9	1.2

Table 8. Average monthly and yearly air temperatures (^{o}C).

Month	Maximum average	Year	Average	Standard error	Minimum average	Year
1	0.2	1989	-6.6	3.6	-15.3	1963
2	1.9	1989	-5.8	3.8	-16.9	1929
3	4.2	1989	-0.7	2.6	-7.7	1952
4	12.3	1950	7.4	2.2	1.3	1929
5	18.7	1975	14.5	2.0	10.4	1980
6	22.0	1964	17.7	1.7	14.4	1933
7	24.3	1936	19.2	1.6	16.1	1979
8	21.7	1929	18.4	1.4	15.1	1926
9	17.1	1937	13.5	1.5	10.6	1959
10	11.4	1935	7.2	1.8	3.0	1946
11	5.4	1926	1.4	2.0	-3.1	1956
12	2.7	1960	-3.3	2.6	-9.7	1933
year	9.1	1975, 1989	6.9	0.9	5.0	1933

Table 9. Quantity of precipitation.

Month	Quantity of precipitation (mm)
January	25
February	24
March	25
April	35
May	47
June	60
July	74
August	64
September	40
October	34
November	45
December	35
year	508

Table 10. Number of days with dust storms[a].

Month	Mean days (%)	Standard deviation	Historic maximum	Year of maximum
February	0.04	0.3	2	1969
March	0.06	0.2	1	1971
April	0.2	0.4	2	1967
May	0.3	0.6	3	1958
June	0.3	0.5	2	1947
July	0.1	0.3	1	1959
August	0.2	0.4	2	1959
September	0.09	0.3	1	1959
October	0.07	0.3	1	1963
November	0.07	0.3	3	1942
December	0.04	0.3	2	1958
Year	1.5	1.7	6	1959

[a]A dust storm is defined as a wind speed ≥ 10 m s^{-1} at 1 m or ≥ 15 m s^{-1} at 10 m. It requires light soil and an open area.

Table 11. Probability of months and years with and without a dust storm.

	Probability (%)	
Month	with dust storm	without dust storm
February	6.2	93.8
March	2.1	97.9
April	13.8	86.2
May	27.3	72.7
June	31.7	68.3
July	13.8	86.2
August	12.0	88.0
September	5.9	94.1
year	72.1	27.9

TABLES OF TEST DATA

Table 12. Monthly average concentrations of ^{137}Cs at specified locations (μBq m^{-3}).

Year	Month	Pripyat	Kiev	Polesskoe
1987	January	-	120	640
	April	-	180	2500
	August	2349	60	360
	October	8322	70	350
1988	January	5161	28	220
	April	5588	52	1240
	August	1072	24	490
	October	1605	23	460
1989	January	345	14	90
	April	3107	15	280
	August	564	12	250
	October	491	12	140
1990	January	339	6	95
	April	863	16	210
	August	580	22	140
	October	590	12	130
1991	January	225	12	140
	April	960	12	250
	August	470	12	140
	October	567	8	75
1992	January	249	14	117
	April	229	10	103
	August	490	16	243
	October	330	8	71

Table 13. Annual average concentrations of ^{137}Cs at specified locations ($\mu Bq\ m^{-3}$).

Location	Year	Mean	Lower bound[a]	Upper bound[b]
Pripyat	1987[c]	4118	838	7398
	1988	2931	670	5192
	1989	940	143	1737
	1990	514	313	715
	1991	446	153	739
	1992	407	137	677
	1993	398	98	698
Kiev	1987	103	47	159
	1988	28	17	39
	1989	18	4	32
	1990	14	6.9	21.1
	1991	10	7	13
	1992	14	7	21
Polesskoe	1987	950	70	1830
	1988	410	120	700
	1989	230	120	340
	1990	130	69	191
	1991	104	48	160
	1992	123	36	210

[a] Mean minus 1 standard deviation.
[b] Mean plus 1 standard deviation.
[c] July to December for Pripyat, January to December for Kiev and Polesskoe.

Table 14. Average radionuclide concentrations in air (μBq m^{-3}) and resuspension factors (m^{-1}) in Kiev in December 1991.

Radionuclide	Mean	Lower bound[a]	Upper bound[b]
<u>Concentration in air (μBq m^{-3})</u>			
^{137}Cs	4.8	0.4	9.2
^{90}Sr	0.16	-0.09	0.41
$^{239+240}Pu$	0.03	-0.01	0.07
<u>Resuspension factor (m^{-1})</u>			
^{137}Cs	1.5×10^{-9}	5×10^{-10}	2.5×10^{-9}
^{90}Sr	2.4×10^{-9}	-1.1×10^{-9}	5.9×10^{-9}
$^{239+240}Pu$	2.7×10^{-9}	-1×10^{-9}	6.4×10^{-9}

[a] Mean minus 1 standard deviation.
[b] Mean plus 1 standard deviation.

Table 15. Annual average resuspension rates (s^{-1}) and resuspension factors (m^{-1}) for ^{137}Cs in Zapolie in 1986 and 1992.

Year	Mean	Lower bound[a]	Upper bound[b]
<u>Resuspension rate (s^{-1})</u>			
1986	1.0×10^{-9}	3.0×10^{-10}	1.7×10^{-9}
1992	3.8×10^{-11}	1.3×10^{-11}	6.3×10^{-11}
<u>Resuspension factor (m^{-1})</u>			
1986	7.7×10^{-8}	5.6×10^{-8}	9.8×10^{-8}
1992	7×10^{-10}	2×10^{-10}	1.2×10^{-9}

[a] Mean minus 1 standard deviation.
[b] Mean plus 1 standard deviation.

Table 16. Annual average resuspension factors (m^{-1}) for ^{137}Cs measured at the city of Chernobyl in 1986 (after May 20) and 1987-1991.

Year	Mean	Lower limit	Upper limit
1986	3.30×10^{-8}	5.3×10^{-9}	8.30×10^{-8}
1987	8.2×10^{-9}	1.3×10^{-9}	1.70×10^{-8}
1988	3.2×10^{-9}	4×10^{-10}	7.0×10^{-9}
1989	1.4×10^{-9}	2×10^{-10}	3.4×10^{-9}
1990	6×10^{-10}	8×10^{-11}	1.5×10^{-9}
1991	8×10^{-10}	1×10^{-10}	1.8×10^{-9}

Table 17. Resuspension factors (m^{-1}) experimentally determined in the 30-km zone following the Chernobyl accident.

Date	Radionuclide	Resuspension factor
14 - 17 September 1986	^{137}Cs*	$(17 \pm 19) \times 10^{-8}$
	^{106}Ru	$(23 \pm 16) \times 10^{-8}$
	^{144}Ce	$(19 \pm 24) \times 10^{-8}$
	^{95}Zr	$(20 \pm 23) \times 10^{-8}$
25 September 1991	^{137}Cs	
	First Point:	$(4.3 \pm 2.2) \times 10^{-10}$
	Second Point**:	$(2.4 \pm 1.0) \times 10^{-10}$

* Mean over 10 points and three days.

** Mean of six values of measured during one day.

Table 18. Characteristics of the annual changes in air concentrations.

SITE	YEARS						
	1987	1988	1989	1990	1991	1992	1993
	Annual Average Concentrations (Standard Deviation), µBq m^{-3}						
Pripyat	4118	2931	940	514	446	407	398
	(3280)	(2261)	(797)	(201)	(293)	(270)	(300)
Polesskoe	950	410	230	130	104	123	-
	(880)	(290)	(110)	(61)	(56)	(87)	-
Kiev	103	28	18	14	10	14	-
	(56)	(11)	(14)	(7.1)	(3)	(7)	-

	1987-1988	1988-1989	1989-1990	1990-1991	1991-1992	1992-1993
	Absolute Annual Change, $(\bar{c}_{i+1} - \bar{c}_i) / \Delta t$, µBq m^{-3} y^{-1}					
Pripyat	-1190	-1990	-426	-68	-39	-9
Polesskoe	-540	-180	-100	-26	+19	-
Kiev	-75	-10	-4	-4	+4	-
	Relative Annual Change, $(\bar{c}_{i+1} - \bar{c}_i)\bar{c}_{i+1}^{-1} / \Delta t$, y^{-1}					
Pripyat	-0.40	-2.12	-0.83	-0.15	-0.096	-0.02
Polesskoe	-1.32	-0.78	-0.77	-0.25	+0.15	-
Kiev	-2.7	-0.56	-0.29	-0.40	+0.29	-
	Ratio of Annual Difference to Standard Deviation, $\left|(\bar{c}_{i+1} - \bar{c}_i) / \sigma_{i+1}\right|$					
Pripyat	0.53	2.5	2.1	0.23	0.14	0.03
Polesskoe	1. 9	1.6	1.6	0.46	0.22	-
Kiev	6.82	0.71	0.56	1.33	0.57	-

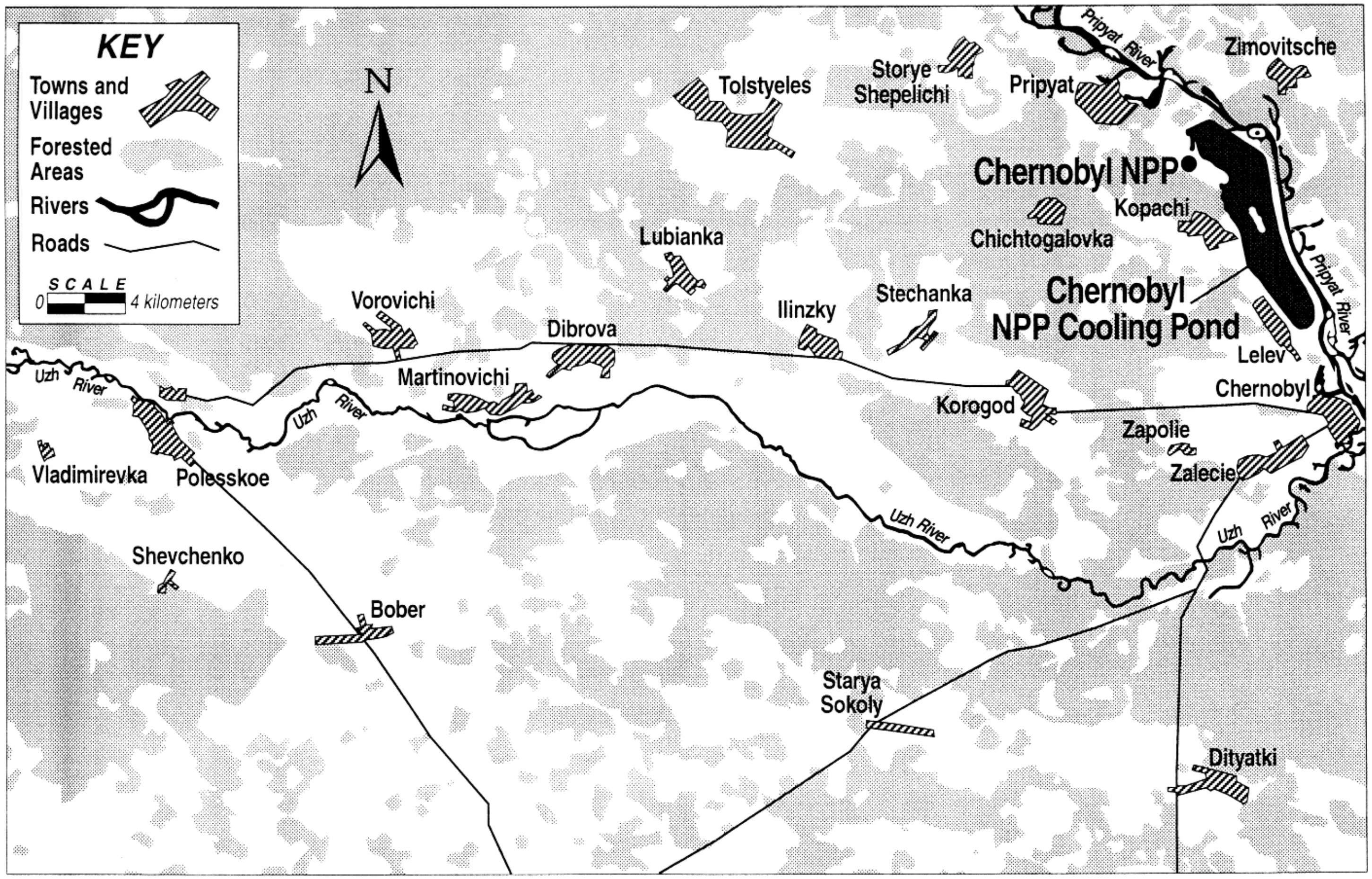

Figure 1. Map of the Polesskoe District (Ministry of Defense of Ukraine, 1992).

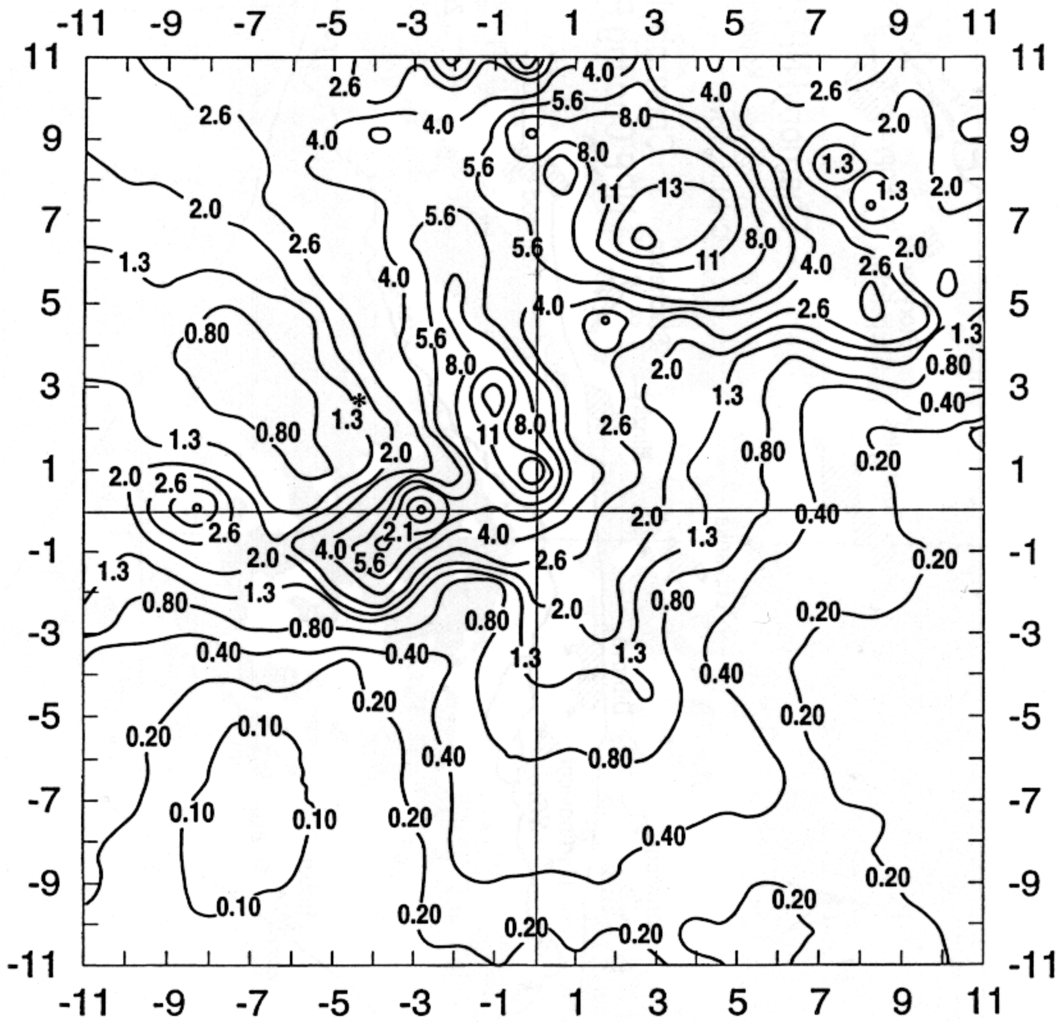

Figure 2. Map of the surface contamination of ^{137}Cs within 10 km of the Chernobyl Nuclear Power Plant ($MBq\ m^{-2}$). The center of the figure is the Chernobyl NPP; the asterisk (approximate coordinates —4.5, 2.5) is the observation site in the center of Pripyat. The numbers around the edge indicate distance in km from the epicenter

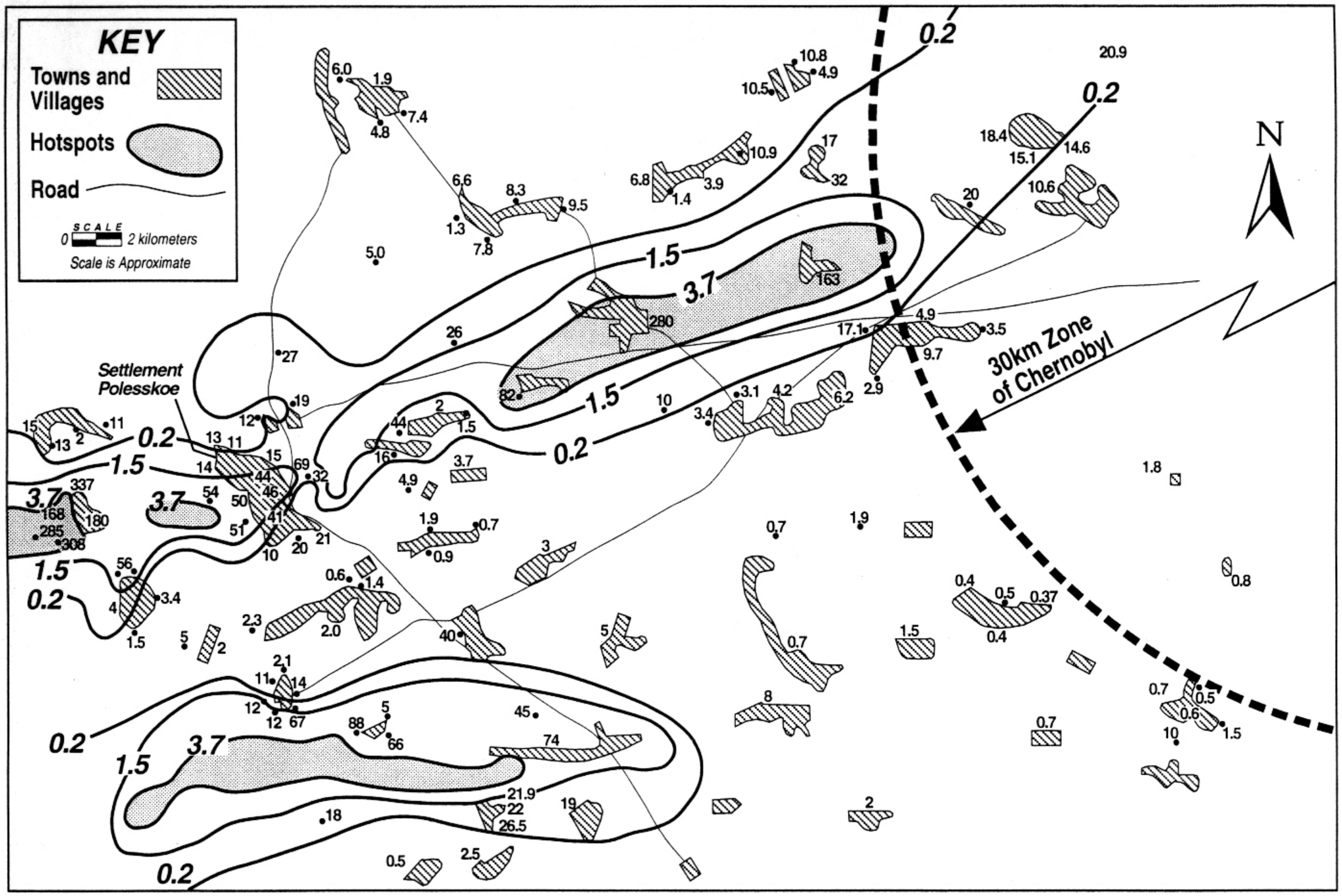

Figure 3. Map of ^{137}Cs contamination in the district of Polesskoe in 1987 ($MBq\ m^{-2}$). The small numbers near the inhabited areas are given in $Ci\ km^{-2}$ ($1\ Ci\ km^{-2} = 3.7 \times 10^4\ Bq\ m^{-2}$). The hot spots are as follows: South, Bober-Shevchenko hot spot; East, Vorovichi hot spot; and West, Vladimirevka hot spot.

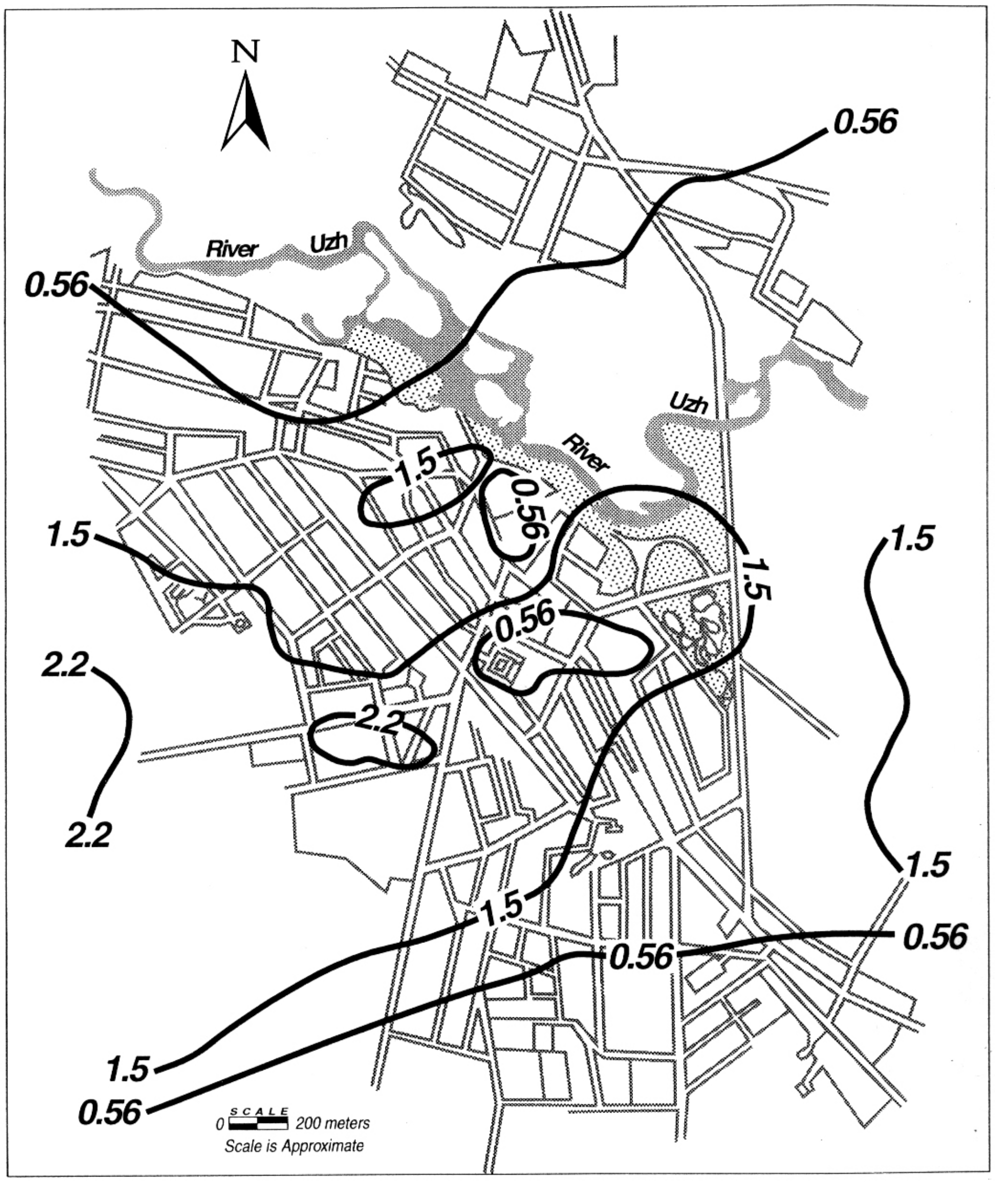

Figure 4. Map of ^{137}Cs contamination in the settlement of Polesskoe (MBq m^{-2}).

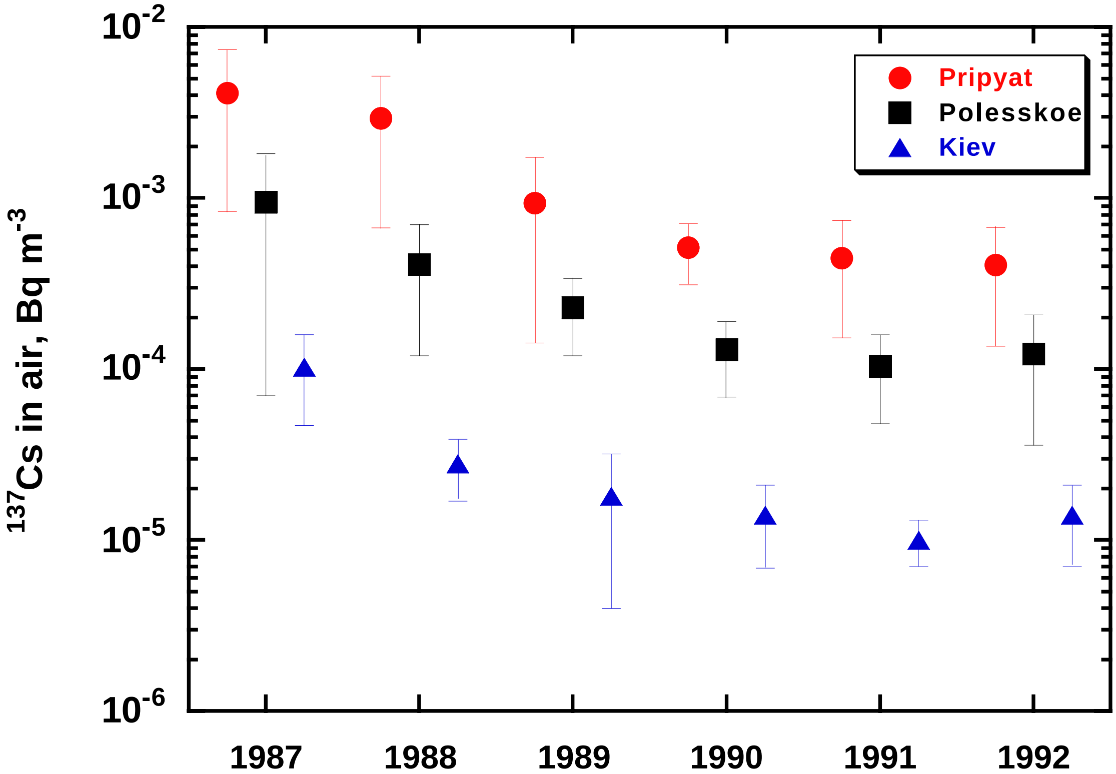

Figure 5. Measured annual average concentrations of ^{137}Cs in air in Pripyat, Polesskoe, and Kiev.