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ASSESSMENT OF THE EFFECT OF TEMPORARY STORAGE SITES FOR RADIOACTIVE WASTES ON THE TERRITORY OF THE RUSSIAN SCIENCE CENTER KURCHATOV INSTITUTE ON THE POPULATION AND THE ENVIRONMENT

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The presence of nuclear objects in an urban environment, next to homes, always creates stress. The presence of the Russian Science Center Kurchatov Institute in Moscow confirms this. In this article, an attempt is made to show by a computational-analytical method the origin of this hazard, and the real radiation levels, additional to the natural background radiation, from the temporary storage sites are presented. It is shown that under the present conditions the contents of the temporary storage sites do not present any danger to the people living nearby.

The Russian Science Center Kurchatov Institute is the oldest and one of the largest nuclear centers in the Moscow region. Its territory contains nine research reactors, some of which continue to operate, 17 critical assemblies, a laboratory for radiation materials science, a storage site for spent nuclear fuel, and trench-type sites for temporary storage of radioactive wastes with unavoidable contamination of the surface layer of the storage section. At the moment when the work described in the present paper was performed the activity of radionuclides on the temporary section was analytically estimated to be 0.1 MCi [1].

The people living in the adjoining area are concerned about the possible consequences of such a nearby section for temporary storage of wastes (Figs. 1, 2). The territory between the barrier of the section for temporary storage of wastes and the outer fence of the institute is now a city parking lot, a city road along the territory of the institute is located several meters from the fence. At "peak" hours up to 3000 automobiles per hour pass along this road.

In 2003, the International Institute of Applied Systems Analysis obtained a grant to investigate the effect of the storage sites for radioactive wastes located on the territory of the Kurchatov Institute in the following directions:

- collection, analysis, and comparison of accessible data concerning the description of the section for temporary storage of wastes and the characteristics of the surrounding environment;
- simulation of the migration of radionuclides as a result of soil erosion by surface waters under extreme weather conditions;

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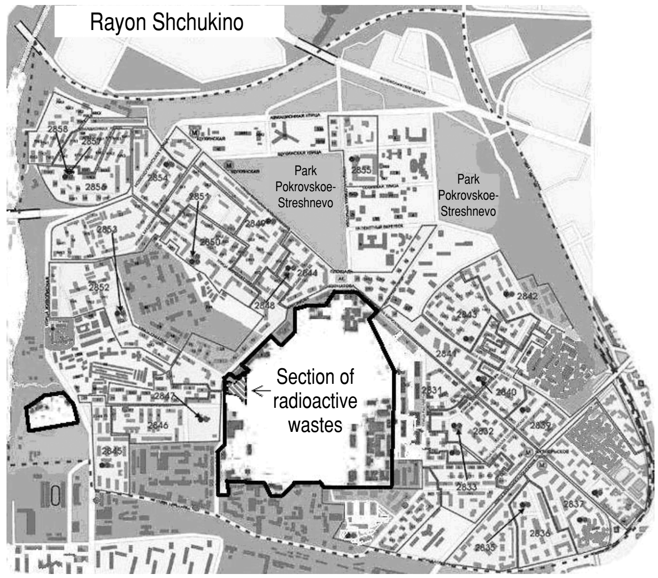

Fig. 1. Arrangement of the Kurchatov Institute and the section for storage of radioactive wastes on its territory.

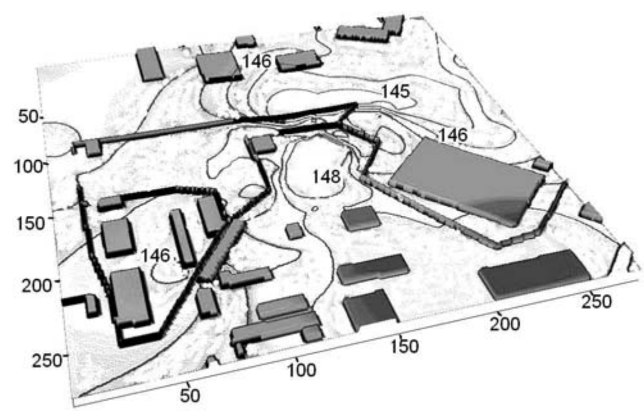

Fig. 2. Section for temporary storage of wastes.

• analysis of the main pathways for radiation effect on the critical population groups and calculation of the dose loads as a result of migration of radionuclides from the territory of the temporary storage section.

In the present paper, inferences are drawn from the investigations performed as part of this program.

Basic Information on the Section for Temporary Storage of Wastes and Simulation of the Surface Transport of Radionuclides. There is not enough information for the sites, which were formed over a period of several decades, concerning the characteristics of the disposal and the territory itself. Consequently, the missing information was obtained using computational-analytical methods. In so doing, a situation on the territory of the section for temporary storage, as it stood by 2001 up to the start of rehabilitation work, was examined. The existing data and some production documents, known before 2002, were used to estimate the radiation characteristics of the contaminated territory.

At the present time, rehabilitation work, including work involving a change of the relief, is being performed on this section. Because of this work, the actual data on the characteristics of the wastes and the territory of the section are also being refined.

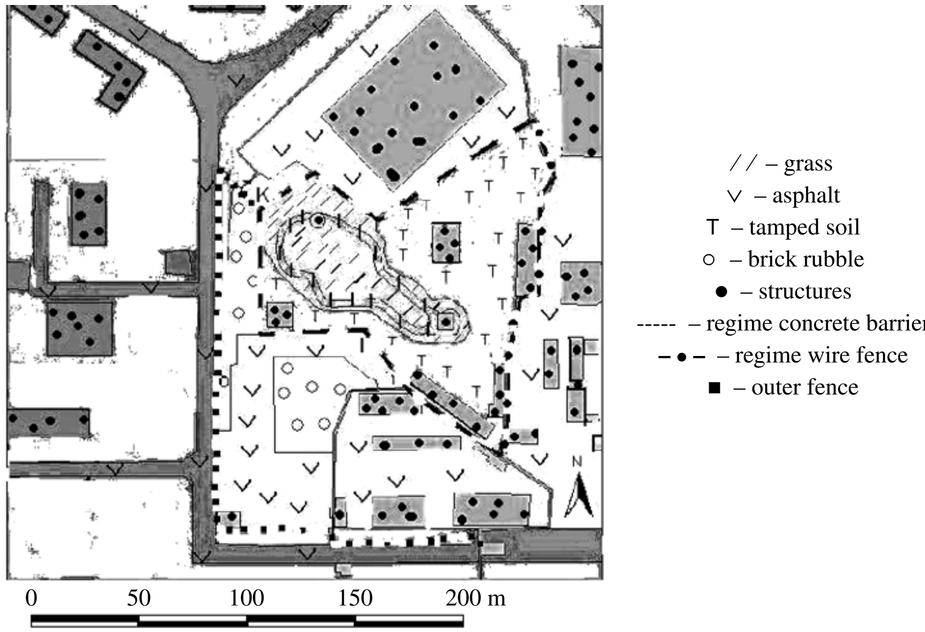

Fig. 3. Territory of the section for temporary storage of wastes and the adjoining city territory.

The section for temporary storage is located on the main site of the institute, and is enclosed by a fence. Its area is about 1.1 ha (Fig. 3). The boundary of the institute passes along the outer fence. The territory between the regime and outer fences is a city parking lot. The closest occupied building is 100 m away.

The purpose of the simulation of the surface transport was to investigate the erosion of the surface layer on the section for temporary storage of wastes, the redistribution of radioactive contamination within the section, and the possible washing off of radionuclides from its territory by rain.

Considering the size of the territory, the complicated relief of the site, and the presence of a large number of buildings, structures, and fences, which disrupt surface runoff, the spatial step for the simulation was taken to be 1×1 m. The LISEM program was used for the simulation. This program was developed at Utrecht University (Netherlands) as part of the European project Spartacus and is based on taking account of the physical mechanisms of surface-water runoff and the corresponding soil erosion [2].

The basic information on the surface contamination of the section was obtained from measurements of the γ-ray exposure dose rate. The measurements were performed with a step of 10 m at a distance of 1–1.5 m from the surface (Fig. 4) [3]. The surface contamination with ^{137}Cs was obtained by scaling the exposure dose rate assuming local uniformity of the contamination of a 15-cm thick surface layer. The scaling procedure was based on satisfactory agreement between the measured dose rate at nine points of the territory and the computed dose rate based on measurements of the ^{137}Cs concentration at the same points. The ^{90}Sr content in the soil was determined according to the ^{137}Cs contamination and using the averaged ratio between the concentrations of ^{137}Cs and ^{90}Sr, measured at seven points. Of course, such a statistical sample is inadequate since the contamination of the site is nonuniform: the range of variation of the exposure dose rate was 30–3000 μR/h, and in some locations this level was substantially exceeded. Nonetheless, it was assumed that the values obtained can be used as a first approximation.

Another parameter, whose uncertainty strongly influences the results of the modeling, is the precipitation infiltration coefficient. The range of variation of this parameter, measured at different times and by different methods, is large. Unfortunately, the limited information on the details of the experimental investigations, performed in previous years, made it impossible to make a quantitative comparison of the results obtained by various procedures for determining the infiltration rate. The transport was simulated using the infiltration characteristics of urbanozems, which on the average satisfactorily

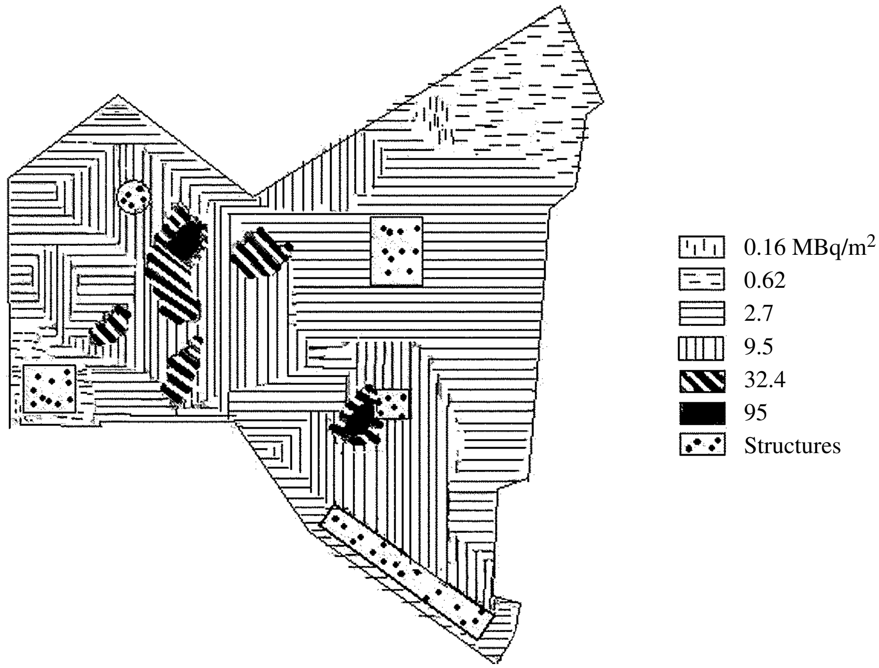

Fig. 4. Chart showing the initial ^{137}Cs contamination of the section for temporary storage of wastes.

describe the grass-covered sections for temporary storage of wastes. For these sections, denoted in Fig. 3 as grass, the infiltration rate of surface waters is taken to be 40 mm/h for moist soil and 150 mm/h for dry soil. For the rest of the section, designated as tamped soils, the level of production work is characteristically high, which results in tamping of the ground and lower filtration. Filtration in these sections was taken to be 40 mm/h, and the maximum moisture content of the soil was assumed to be 35%.

The scenarios of the transport of radionuclides by surface waters were chosen on the basis of an analysis of the precipitation intensity, the properties of the surface layer at the site and the state of the regime fence of the section for temporary storage of the wastes, which is an engineering barrier in the path of possible water runoff. The upper limit on the intensity of precipitation for strong or torrential rains was taken to be 100 mm/h. According to meteorological data, this corresponds to the maximum for the Moscow region over the last 37 yr. The intensity 35 mm/h was chosen as the lower limit from simulating the precipitation, which corresponds to an average, over the last 37 yr, maximum hourly precipitations.

Several scenarios of the status of the concrete regime fence were examined. In principle, it is not impermeable to water: 5–10 mm cracks are actually present on each two-meter section of the concrete barrier. The eastern perimeter of the fence (wire grid) is not an obstacle for rain water. To simplify the analysis of the surface runoff of rain water, a scenario where one of the sections of the concrete barrier is missing because, for example, repair work is being performed or its foundation was washed out by erosion, was examined. A preliminary analysis of the directions of rain waters on the section for temporary storage of wastes in the adjoining territory, performed on the basis of a digitized map of the relief, revealed several locations in the fence which can be damaged by larger than expected water erosion and, therefore, are locations where soil erosion occurs or repair work must be performed. The considerations presented above formed the basis for 16 scenarios for simulating the erosion by surface waters, presented in Table 1:

- strong or torrential rain (100 mm), typical rain (35 mm);
- state of the soil before the rain – moist (variant 40), dry (variant 150);
- state of the barrier on the territory of the section – the concrete part is impermeable to water, the barrier is not an obstacle to rain water runoff along its entire perimeter, the concrete part of the barrier is everywhere impermeable to water, except for a hypothetical opening 1 m wide near the location with the greatest probability of washouts corresponding to the relief and the map of the runoff of rain water (the points I and K of the regime fence).

TABLE 1. Results of the Simulation of the Outflow of Radionuclides from the Territory of the Section for Temporary Storage of Wastes

Rain, mm/h	State		^{137}Cs outflow			^{90}Sr outflow		
	of the soil	of the barrier	onto the territory of the institute, 10^5 Bq	onto the city parking lot, 10^7 Bq	settling on a city street, 10^2 Bq/m^2	onto the territory of the institute, 10^4 Bq	onto the city parking lot, 10^7 Bq	settling on a city street, 10^2 Bq/m^2
100	Moist	Without cracks	220	6.3	74	430	1.3	4.2
		No fence	0	7.8	–	0	1.5	–
		I	0	42	19	0	8.3	11
		K	0	50	16	0	10	9.1
	Dry	Without cracks	0.63	0	1.4	0.91	0	0.8
		No fence	0	5.6	–	0	1.1	–
		I	0	11	8.9	0	2.1	5
		K	0	24	8.4	0	4.7	4.8
35	Moist	Without cracks	0	0	–	0	0	0
		No fence	0	2.7	–	0	0.54	–
		I	0	1.1	1.9	0	0.22	1.1
		K	0	8	1.9	0	1.6	1.1
	Dry	Without cracks	0	0	0	0	0	0
		No fence	0	2.7	–	0	0.54	
		I	0	1.1	1.9	0	0.22	1.1
		K	0	8	1.9	0	1.6	1.1

Note. A dash corresponds to variables which cannot be obtained from the model.

TABLE 2. Yearly Irradiation Dose to the Critical Population Groups as a Result of Radionuclides Being Washed Off the Section for Temporary Storage of Wastes by Rain

Critical population group	External irradiation, 10^{-6} Sv/yr	Internal irradiation, 10^{-7} Sv/yr	Total, 10^{-6} Sv/yr	Fraction of yearly dose limit, %
Scenario of strong or torrential rain				
Automobile drivers on the parking lot	7–55	0.46–4.1	7.1–54.4	0.7–5.4
Workers on the parking lot	17.6–132	1.1–10	17.7–133	1.8–13.3
Pedestrians on the contaminated section of the street	Up to 6.2	0.015–0.33	Up to 6.24	Up to 0.62
Scenarios of medium-intensity rain				
Automobile drivers on the parking lot	Up to 7.3	0.1–0.6	Up to 7.4	Up to 0.7
Workers on the parking lot	Up to 17.6	0.23–1.6	Up to 17.8	Up to 1.7
Pedestrians on the contaminated section of the street	0.164	0.02	0.17	0.017

Estimates of the Radiation Effect with Wash-off of Radionuclides. The results of the simulation show that for extremely strong rain the section for the temporary storage of wastes can be flooded by rain water and radionuclides can be washed off the surface. The flow of contaminated water reaches the regime fence of the section and spreads along the territory between the barrier of the section for temporary storage and the outer fence of the institute, where the city parking lot is located. The contamination of the parking lot, whose area is 6200 m^2, is due to sedimentation of radionuclides washed off in the form of suspensions.

In addition, the contaminated waters partially pass through the service opening in the outer fence and reach the street adjoining this fence, flow along this street and enter the local flood zone which forms on the street during rainy periods. The flood area, calculated taking account of the permeability of the water collectors, is 3500 m^2. The water volume in the flood zone is estimated to be 2500–2700 m^3. The contamination of the street adjoining the outer fence of the institute is mainly due to radionuclides washed off in soluble form. This contamination was calculated assuming that the contaminated rain waters remain on the street for several hours, before they enter the drainage system, and the radionuclides over this time are adsorbed on the bottom of the flood zone.

Under urban conditions, the main pathways of irradiation of the public due to the contamination of local sections are external γ radiation from the contaminated ground surface and irradiation resulting from inhalation of radionuclides entering the air as a result of resuspension. The critical groups of the population in these situations are people living in the houses closest to the territory of the institute, and the users of and workers on the parking lot. The calculation of the dose loads was performed in accordance with the ICRP recommendations [4, 5].

The following results were obtained for scenarios with strong or torrential rains:

- in the parking lot the additional, with respect to the background, exposure rate of γ irradiation of drivers can be 0.02–0.15 μSv/h, depending on the scenario; this is actually a doubling of the exposure dose rate (the average measured external γ radiation on the territory of the institute close to the section for temporary storage of wastes is about 13.7 μR/h [1]), and it can be easily found by dosimetric monitoring;
- on the contaminated section of the street the exposure dose rate for the critical population group is low (maximum 0.017 μSv/h), and can hardly be noticed by dosimetric monitoring.

For scenarios of medium-intensity rain, the calculations showed a negligible increase of the external irradiation on the parking lot (up to 0.02 μSv/h in the scenario near the location of the wash-off) and an unnoticeable increase in the exposure dose rate on the section of the street which is flooded during rainy weather.

The inhalation pathway of irradiation is due to the formation of local radioactive deposits, which can become resuspended and easily rise into the air, forming radioactive aerosols. The inhalation dose was calculated using well-known procedures [5–7]. The difference was that the more conservative value 10^{-6} m^{-1} was used for the initial coefficient of resuspension since the initial deposits containing radionuclides are moist and cannot immediately be picked up into dust.

The computed dose rates from inhalation of ^{137}Cs and ^{90}Sr for automobile owners and personnel located on the parking lot are $(5–44)\cdot10^{-11}$ Sv/h and $(7.8–69)\cdot10^{-11}$ Sv/h, respectively. On the contaminated section of the street the maximum inhalation dose for an adult does not exceed $3\cdot10^{-12}$–$4\cdot10^{-11}$ Sv/h.

The hypothetical yearly irradiation dose to the local critical population group was calculated on the basis of a pessimistic assumption that the initial irradiation levels due to washoff of radionuclides from the territory of the section remain for the entire subsequent year. It was assumed that during the year the automobile driver is present on the parking lot daily for 1 h, a worker in the parking lot spends 4 h on the parking lot, and pedestrians spend 1 h on the contaminated section of the street (Table 2).

Conclusions. As a whole, the analysis showed that the data on the territory of the section for temporary storage of wastes are inadequate for detailed simulation of surface transport. This fact is a reflection of the real situation. Consequently, the initial data were mostly obtained by the computational-analytical method.

The analysis showed the following:

- the topography of the section for temporary storage of wastes, the city territory lying next to it, and the absence of a special drainage system do not preclude the torrential-rain waters from flowing out of the section; the surface contamination outside the territory of the section can be tens of kBq/m^2 under unfavorable weather conditions;
- the redistribution of the surface contamination within the territory of the section can be appreciable (up to 100 m^2 of the surface can be contaminated twice as much after a rain storm, Fig. 5);
- additional dose loads to the critical population groups do not exceed 13% of the yearly dose limit; however, an increase of the radiation background level in itself can act as a psychological factor which concerns the public.

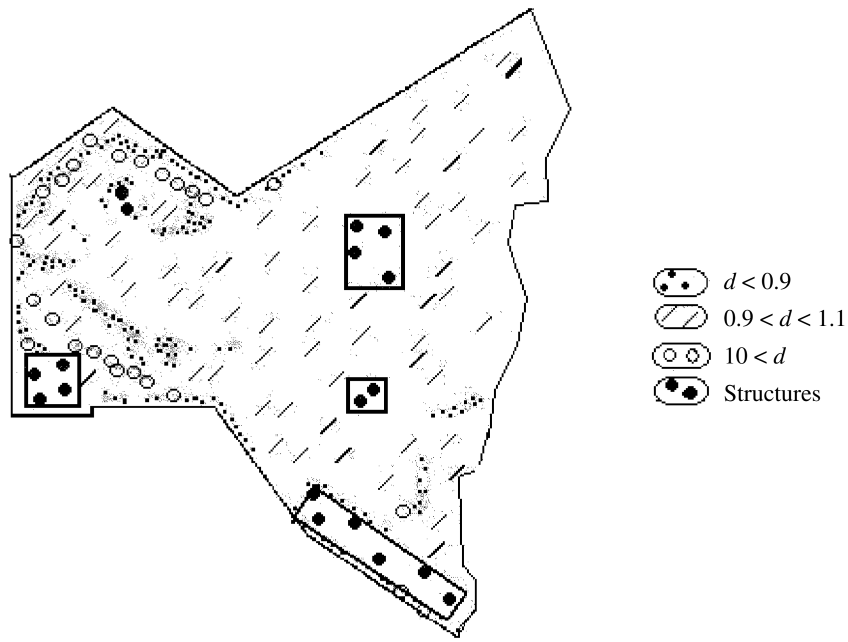

Fig. 5. Redistribution of radionuclides on the territory of the section for temporary storage of wastes for scenario I – moist soil, strong rain, ratio between the obtained and initial contamination with ^{137}Cs (d).

At the same time, the rehabilitation, currently being performed, of the territory of the section (removal of the contents of the storage sites and contaminated soil) can substantially improve the radiation conditions. To make a complete estimate of the influence of radiation contamination on the adjoining territory, these investigations should be supplemented with data on the migration of radionuclides in ground water. This is especially important considering the possible degradation of temporary storage sites. It is precisely such comprehensive investigations that serve as a basis for the rehabilitation of the section for temporary storage of wastes.

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