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HYDROGEOLOGICAL INFLUENCES ON RADIONUCLIDE MIGRATION FROM THE
MAJOR RADIOACTIVE WASTE BURIAL SITES AT CHERNOBYL
(A REVIEW)

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ABSTRACT

This paper summarizes the recent hydrogeological investigations of several research organizations on waste confinement at the major radioactive waste (RW) burial sites immediately adjacent to the Chernobyl Nuclear Power Plant (Ch.NPP). Hydrogeological conditions and radiologic ground-water contamination levels are described. Ongoing ground-water monitoring practices are evaluated. The chemical and physical characteristics of the radionuclides within the burial sites are considered. Ground water and radionuclide transport modeling studies related to problems of the RW disposal sites are also reviewed. Current concerns on future impacts of the RW burial sites on the hydrogeological environment and water resources of the Ch.NPP area are discussed.

1. INTRODUCTION

This review paper assesses the role of the emergency RW burial sites created during mitigation of the consequences of the accident at Unit #4 of the Chernobyl NPP (Ch.NPP) as a source of contamination of the hydrogeological environment and radionuclide migration in groundwater. This analysis is based on the results of field surveys, laboratory studies and mathematical modeling. The problems and uncertainties connected with such an assessment are considered and discussed.

The main sources for this review were reports by the Institute of Industrial Technologies (Libov et al., 1991; Il'ichev et al., 1992) and the Radium Institute (Krivokhatski et al., 1992a, 1992b), unpublished data of the Department of the Dosimetric Control (DDC) of the Research and Industrial Association "Pripyat", as well as the studies carried out by the Institute of Geological Sciences of the Ukrainian Academy (Dgepo et al., 1992; 1993).

2. HISTORICAL BACKGROUND

The major RW burial sites in the Ch.NPP zone were created in 1987 during decontamination of the area immediately adjacent to the NPP. The clean-up activities were carried out in order to prevent "Red Forest" (i.e., pine trees killed by radiation) fires and to lower radiation levels at the ground surface. The clean-up resulted in the removal of the upper 10-15 cm thick soil layer and demolition of vegetation and buildings within about an 8 km² area. The radioactive wastes resulting from this clean-up, with a total volume of approximately 10⁶ m³, were disposed locally in trenches and/or artificial mounds directly into the local sandy

soil without any use of isolating liners. In total, about 600 of these burial sites were constructed (Libov et al., 1991). The decontamination activities resulted in at least a 10-fold reduction of the ground surface radiation levels (Il'ichev et al., 1992).

In 1990, the DDC inventoried the RW disposal sites within the 30 km Chernobyl exclusion zone. The burial sites located in the zone immediately adjacent to the Ch.NPP were grouped into six main Sites of Temporary Radioactive Waste Localization (STRWL): "Building-Base", "Red Forest", "Yanov", "Pripyat", "Oil-Base", "Sandy Plateau", and the "Ch.NPP site" (Fig. 1, Table 1). The total amount of radionuclides stored in the STRWL was estimated at $5 \cdot 10^4$ Curie (Ci). This rough estimate was based on ground-surface contamination values produced by radioactive fallout before any clean-up efforts. The quantity of radionuclides buried in the STRWL is comparable to that in the special RW storage facilities that contain radioactive material from the Unit #4 reactor (i.e., the "Podleony", "Complexny" and "Burakovka" facilities), as well as to contamination dispersed with radioactive fall-out over the entire 2827 km² Chernobyl exclusion zone (Libov et al., 1991). The clean-up activities of 1987 were carried out under emergency conditions by temporarily assigned army units and were poorly documented. In 1990, DDC performed the first inventory of the sites and found that the location of individual trenches had not been mapped. Details of the characteristics and inventories of the stored RW are limited. The interactions of the waste with the ground-water system were poorly understood. These data requirements directed the site investigation and related research activities carried out at the STRWL in the years from 1991 to 1993. By the end of 1993, exploratory surveys have been made for most of the "Red Forest" STRWL and a portion of the "Yanov" STRWL. The rest of STRWL remains uncharacterized.

3. HYDROGEOLOGICAL CHARACTERISTICS OF THE CHERNOBYL NPP ZONE

The RW burial sites are located within the modern flood plain and on the adjacent lowest fluvial terrace of the Pripyat river. The site is characterized by limited relief and surface runoff is minimal. During decontamination efforts the ground surface was sprayed with film-forming chemical compounds to suppress the dust. Localized patches of these films remain. In the years that followed, the affected region was seeded with grass and planted with trees. Most of the young plants have since perished, so the modern vegetation cover at the STRWL is mostly scrubs and weeds (Balashev et al., 1991).

A geologic cross section of the site is shown in Figure 2. The upper part of the section consists of alluvial and fluvio-glacial Quaternary deposits, represented mostly by fine- to medium-grained quartz sands. Beds of sandy-loam and loam material interfinger with the sand units.

The surficial deposits are characterized by rapid lateral and vertical changes in lithology and lithofacies. The Quaternary deposits are underlain by a low permeability, Kiev-stage (Paleogene) clay-rich aquitard. The Quaternary deposits form an unconfined aquifer with a saturated thickness of about 25-30 m, while depth from the ground surface to the water table ranges from 8 to 10 m in the upper portions of the watershed to 0 to 2 m in the

flood plain areas adjacent to the Pripyat River. The seasonal ground-water table fluctuations average from 0.5 to 1.0 m with minimal elevations observed in winter and maximum elevations in spring and summer. Regional hydraulic gradients range from 0.01 to 0.001. Hydraulic conductivities of the sands that form the upper part of the unconfined aquifer range from 1-3 to 8-20 m/day. Ground-water recharge occurs mostly from precipitation. Precipitation values for the study region average 550-600 mm/year. Infiltration recharge is estimated at 50-200 mm/year. In the zone of the Ch.NPP and the town of Pripyat, natural recharge and ground-water flow directions are being altered by artificial factors; leakage from water-supply utility pipes, recharge from the NPP waste water disposal facilities, operation of the drainage systems of the Ch.NPP, etc. The chemical composition of the groundwater is shown in Table 2.

Beneath the Kiev-stage clay aquitard, Eocene sands form a confined aquifer that varies in thickness from 20 to 40 m. Transmissivities in this aquifer are estimated to range from 90 to 200 m²/day. The Eocene aquifer is used as a potable water source for Ch.NPP and Pripyat with production from the Yanov water supply system wells. Differences in potentiometric levels between the unconfined Quaternary and confined Eocene aquifers in the central part of the depression cone that is formed by the Yanov water supply wells reaches 18-20 m (Novikov and Drobnokhod, 1986; Dgepo et al., 1992; Myasnikov et al., 1992). A downward-directed, vertical hydraulic head results across the Kiev-stage aquitard from the production activities.

4. GROUND-WATER MONITORING AT THE STRWL

Approximately 30 observation wells have been installed at the STRWL as part of the ground-water monitoring system for the Ch.NPP zone. Since 1988, the DDC staff has been sampling radionuclide concentrations in the groundwater. Between 1988 and 1990, ground-water levels in wells were not measured systematically. Elevations of ground-water table at the site during the spring of 1991 are shown in Figure 1.

Ground-water monitoring and sampling practices in the Ch.NPP zone suffer from a number of shortcomings (Dgepo et al., 1994): the number of monitoring wells is insufficient, the wells are unevenly distributed within the area of interest, their locations are not well suited to determine local hydrogeological conditions nor to monitor individual disposal sites, design completion of many of the wells is not suited for monitoring purposes, and, until recently, several fundamental ground-water sampling rules were neglected (e.g., wells were not pumped before the sampling). For these reasons, the DDC ground-water monitoring data are incomplete and, at least, locally unreliable.

In 1992-1993, the entire ground-water system surrounding the Ch.NPP was contaminated with strontium-90 with concentrations in the range from $n \times 10$ pCi/l to $n \times 1000$ pCi/l. Cesium-137 concentrations in the groundwater ranged from $n \times 1$ pCi/l to $n \times 10$ pCi/l. One-time sampling revealed trace amounts of plutonium were present in some wells (concentrations $n \times 10$ [-14] - $n \times 10$ [-13] Ci/l) (Skalski et al., 1993). Apparently, release and migration from the RW STRWL was the major mechanism for ground-water contamination by

radionuclides. Measurements of the vertical distribution of radionuclides in the Quaternary deposit have revealed that Sr-90 - the most mobile contaminant - has penetrated the vadose zone less than 20 to 30 cm from the ground surface (Krivokhatski et al., 1992a).

Large-scale radionuclide contamination of the confined aquifer is not observed (Skalski et al., 1993). However, the DDC data has shown increases in Sr-90 concentrations in water pumped by wells of the Yanov water supply system from $n \cdot 10^{-13}$ Ci/l in 1986 to $n \cdot 10^{-11}$ Ci/l in 1992. This implies that there is some hydraulic communication between the upper Quaternary aquifer and the lower Paleogene aquifer. Additional monitoring of this water supply system will help understand the extent of the hydraulic connectivity between these aquifers.

5. CHARACTERISTICS OF BURIAL SITES IN SECTOR NO. 2.1 OF THE "RED FOREST" STRWL

The most large-scale and complex exploratory studies of the RW burial sites were performed in 1991-1992 at the "Red Forest" site by the staff of the Institute of Industrial Technologies (Libov et al., 1991; Il'ichev et al., 1992; Myasnikov et al., 1992) and the Radium Institute (Krivokhatski et al., 1992a; 1992b). The characteristics of burial sites within Sector No. 2.1 of the "Red Forest" STRWL are better known than for other contaminated areas.

Site description

The "Red Forest" site lies to the west and southwest of the Ch.NPP. About 375 ha of pine forest grew here before the accident. The biomass within the site in 1986 is estimated at $50-53 \cdot 10^3$ m³. As a result of the accident, the trees have received a dose of about 10-100 Gray (Gy). During the clean-up of the site, the trees were cut and bulldozed together with brushwood, litter and topsoil into trenches (Balashev et al., 1991; Vovk et al., 1993).

Sector No. 2.1 has an area of 0.96 km² (Fig. 1). The vegetation cover is represented mostly by shrubs and weeds. In 1991, the radiation levels at the site averaged 2.7 mR/h with maximum values up to 18 mR/h (Il'ichev et al., 1992).

Surficial deposits are composed of medium- to fine-grained quartz sands. Slug-tests on piezometers gave hydraulic conductivity estimates ranging from 0.3 to 9.1 m/day (average value - 3.4 m/day) (Il'ichev et al., 1992). Hydraulic conductivity estimates of 8-15 m/day were obtained earlier for the site from aquifer pump-tests (Novikov and Drobnokhod, 1986). Laboratory porosity determinations resulted in an average value of 0.25 (Krivokhatski et al., 1992a). Hydraulic gradients range from 0.001 to 0.004; the depth from ground surface to water table, 0-4 m; seasonal water table fluctuations, 0.6 - 0.8 m.

Design Peculiarities of the RW Burial Sites

Within the boundaries of the Sector No. 2.1, a total of 57 RW burial places are found, including 49 trenches and 8 artificial mounds. Trenches are not located systematically. They range in length from 24 to 440 m (average, 100-200 m), in width from 8 to 12 m, in depth from 1.5 to 3 m. The top of the disposed wastes (i.e., soil, litter, vegetation) were covered with a 0.2 - 0.6 m thick

layer of alluvial sand. The total volume of the disposed material contained in trenches is estimated to be $10[5] \text{ m}[3]$ with an average density of $1.6 \cdot 10[3] \text{ kg/m}[3]$ (Il'ichev et al., 1992).

Amount of Radionuclides in Burial Sites

According to Il'ichev et al. (1992), the following sources of radioactivity were present in Sector No. 2.1: (a) a thin top soil layer from 0 to 0.05 m; (b) a soil zone at the depth from 0.05 to 0.5 m (unevenness of the ground surface filled up during the clean-up) and (c) trenches and artificial mounds containing RW.

The amount of radionuclides in these sources was evaluated on the basis of surface gamma-ray values and natural gamma-logging the exploratory bore holes. Measured radiation levels were converted to surface contamination densities (and/or mass activities) for each radionuclide using empirical (i.e., experimentally determined) coefficients. The following contributions of different gamma-emitters to the integral dose were determined: Cs-137, 81%; Cs-134, 6.4%; and Ce-144, 6.0%. The remainder of the integral dose is comes from various other radionuclides. Amounts of Sr-90, Pu-238 and Pu-240 were estimated using the following coefficients (activity ratios): $A[\text{Sr-90}]/A[\text{Cs-137}] = 0.62 - 0.7$, $A[\text{Pu-239+240}]/A[\text{Cs-137}] = 0.009 - 0.01$.

Specific activities of the radioactive materials contained in trenches were as follows: Cs-137 and Sr-90, $n \cdot 10[-6]$ to $n \cdot 10[-5]$ Ci/kg, respectively; and Pu-239,240, $n \cdot 10[-7]$ to $n \cdot 10[-8]$ Ci/kg. Calculated amounts of radionuclides in Sector No. 2.1 are displayed in Table 3.

Using data on the amounts of Pu-239 and Pu-240, the quantity of Am-241 contained in Sector No. 2.1 can be evaluated considering that $A[\text{Am-241}]/A[\text{Pu-239+240}] = 0.8 \pm 0.3$ (Krivokhatski et al., 1992). The resulting estimate is about 22 Ci of Am-241.

Ground-water contamination by radionuclides

According to Il'ichev et al. (1992), during 1991-1992, 32 of the 43 explored trenches were permanently or periodically flooded with groundwater. Water rose to 1.7 m above the bottom of the trenches (0.8 - 1.2 m in average). The lower parts of two of the eight artificial mounds in Sector No. 2.1 were also periodically flooded by groundwater.

Ground-water investigations using an auger-sampler have shown that the upper portion of the unconfined aquifer is universally (i.e., both inside and outside of the trenches) contaminated by Sr-90 with radionuclide concentrations in the groundwater exceeding the safety limit by a multiple of 2 to 3. Detectable concentrations of Cs-137 and Pu-239,240 were detected, as a rule, only close to the trenches containing RW. Trace concentrations of Cs-134, Co-60, Ce-144, Sb-125, Am-241 were found in the groundwater (Il'ichev et al., 1992; Krivokhatski et al., 1992b).

6. SPECIATION OF RADIONUCLIDES WITHIN THE BURIAL SITES

Radiologic contamination of the environment in the zone immediately adjacent to the Ch.NPP was formed mainly by the dispersed fuel and graphite "hot" particles of 100-300 micrometer diameter (Dubasov et al., 1991; Krivokhatski et al., 1992b). Fuel particles (FP) belong to two major types: irradiated reactor fuel

(uranium oxides) and aggregates of uranium and zirconium oxides. The second type of particles are more abundant (Dubasov et al., 1992). Most Sr-90 and Pu-239,240 are contained in the FP (Loschilov et al., 1992; Ivanov and Kashparov, 1992). More fusible Cs-137 is present in the zone immediately adjacent to Ch.NPP, both in aerosol condensation and fuel components, roughly in equal proportions (Krivokhatski et al., 1992b).

The specific feature of the radioactive contamination in the Ch.NPP zone is that radionuclides were initially contained in the almost insoluble U-rich fuel matrix. The stability of FP under the influence of natural processes and rates of radionuclide release from these particles were investigated in a number of studies. Laboratory experiments performed at the Radium Institute (Dubasov et al., 1991; Krivokhatski et al., 1992b) have shown that the degree of radionuclide leaching from 100 to 200 micrometer-size FP by water solutions is very small ($n \cdot 0.01$ to $n \cdot 0.001\%$). The aggregate uranium-zirconium particles are even more stable. Radionuclide release rates from the micrometer-size FP and grains of graphite contaminated by fuel were by 1 to 2 times higher. Therefore, it was concluded that the latter components represent more danger. Experiments show that release of radionuclides from FP occurs to a higher degree than dissolution of the UO_2 matrix, that is, diffusive mechanisms of radionuclide leaching may be important (Olkhovik et al., 1992; Krivokhatski et al., 1992b).

Studies on speciation of the radionuclide waste forms in soil samples taken directly from burial sites have shown a rather high degree of mobility (i.e., water-solubility and exchangeability), especially for Sr-90 (Table 5). This is indicative of either the considerable portion of mobile radionuclide forms (not associated with uranium oxides) in the initial fallout (Olkhovik et al., 1992), or of much higher radionuclide release rates from fuel components under field conditions.

Data of Zhdanova et al. (1991) confirms that some biological and biochemical factors may significantly influence the migration behavior of FP. It was found that some species of microorganisms that have been isolated from radionuclide contaminated soils are able to overgrow actively "hot" particles and destroy them within 50 to 150 days.

Cs-137 and Sr-90 show different geochemical behavior after being leached from FP; Sr-90 turns mainly into the mobile exchangeable form, while CS-137 is fixed by clay minerals and organic matter present in soil (Bobovnikova et al., 1990). The high percentage of soluble and exchangeable forms in the RW causes high Sr-90 concentrations in the groundwater in the zone of RW burial sites (Krivokhatski et al., 1992b).

7. SORPTIVE PROPERTIES OF SEDIMENTS IN THE BURIAL SITES

It is well known that mobility of radionuclides in the hydrogeological environment is very dependent on the parameters of radionuclide sorption by sediments. Studies of sorptive properties of sediments in the zone immediately adjacent to Ch.NPP have focused mainly on Sr-90 (Table 6). Investigations of Cs-137 and actinides sorption were carried out by Krivokhatski et al. (1992a; 1992b). The following partition coefficient (K_d) values were determined in batch experiments: CS-137, 60 - 300 ml/g; Pu-239,

240, 20 - 180 ml/g. In these studies, groundwater was used as the experimental solution. Model experiments established that the presence of humic acids from organic sources in solution decrease the sorption of plutonium by a factor of 2 to 3. In the latter case, 85-95% of Pu was present in solution in the colloidal form.

Most of these Kd values were obtained in laboratory batch studies. Because it is practically impossible to maintain thermodynamic conditions, speciation of radionuclides and time scales of the mass-exchange interactions in the laboratory experiments which correspond to field conditions, Kd values may be considered only as a rather rough estimates. Therefore, the following conservative retardation factor estimates for sandy soils of Ch.NPP zone given by Krivokhatski et al. (1992a) seem reasonable: Sr-90, R=5 (Kd=0.5 ml/g); Cs-137, R=100 (Kd=10 ml/g), Pu-239,240, R=30 (Kd=3 ml/g, in presence of humic acids), where "R" is the retardation factor.

8. GROUND-WATER FLOW AND RADIONUCLIDE TRANSPORT MODELING STUDIES

Groundwater modeling

In 1991-1993, a system of multiple-scale ground-water flow numerical models of the Ch.NPP zone was developed at the Institute of Geological Sciences: a regional model (60-km zone, grid spacing 3 km), a local model (15-km zone, spacing 500 m) and a site model (5-km zone, grid spacing 250 by 100 m) (Dgepo et al., 1992; Skalski et al., 1993). These models were used for predicting hydrogeological conditions and for evaluating the ground-water monitoring system in the Chernobyl exclusion zone. A number of questions associated with the STRWL were also investigated.

The analysis of hydrogeological conditions, evaluation of mitigative measures and analysis of factors contributing to the increase of ground-water levels and flooding of trenches with RW at the "Red Forest" site is of interest. The following observations are made: minor influence to ground-water movement was caused by the slurry wall near the Ch.NPP, a decrease of evapotranspiration has resulted from forest demolition, a decrease of the yield of the Yanov water supply system has occurred (Il'ichev et al., 1992; Dgepo et al., 1992, 1993). The latest modeling-based studies have shown that the slurry wall does not significantly alter the ground-water levels and flow directions in the zone of the "Red Forest". The same is true with respect to post-accident changes in the water yield from the Eocene aquifer. Increase in ground-water levels (up to 1 - 1.5 m) may be caused by cessation of functioning of the drainage wells at the site where the fifth reactor was being built before the accident. Ground-water model calibration resulted in ground-water recharge estimates for the "Red Forest" site of about 80-100 mm/yr (Skalski et al., 1993).

Radionuclide migration modeling from the burial sites

Dgepo et al. (1992, 1994) performed Sr-90 transport modeling from the STRWL using a mathematical model accounting for advective transport, hydrodynamic dispersion, sorption, decay and a finite amount of radionuclide in the burial sites. Predictions were based on a number of conservative assumptions: all RW contacted the groundwater; maximum values were assigned to the ground-water flow velocities; RW burial sites were considered as areal sources of

ground-water contamination; radionuclides were uniformly distributed over the disposal sites; and the process of Sr-90 leaching from FP was described by the first-order equation (Bobovnikova et al., 1990). The period of half-leaching of Sr-90 from FP was taken in the range from 5 to 10 years (Dolin et al., 1990). For the rest of model parameters the following estimates were used: $K_d = 0.5 - 2$ ml/g, flow velocity 0.04 m/day, and longitudinal dispersivity = 10 m.

Groundwater that percolates from the RW STRWL discharges either in the Pripyat River or the Ch.NPP drainage wells. Even according to worst-case scenarios, significantly contaminated water from the major burial sites, "Building-Base" and "Red Forest", will not reach the Pripyat River over the next 50 years. However, Sr-90 discharges of about $n \cdot 0.1 - n \cdot 1.0$ Ci/year is possible in the next 10-20 years into the Pripyat River from the burial sites "Oil-Base", "Pripyat", and "Sandy Plateau". Predicted discharge of Sr-90 into the drainage wells around the Ch.NPP is estimated at $n \cdot 10$ Ci/year with the produced water being released to the cooling pond. Filtration discharges from the cooling pond eventually enter the Pripyat River.

9. CONCLUSIONS

Radioactive waste burial sites represent the source of radiological contaminants to groundwater, especially Sr-90. Sr-90 is the critical radionuclide from the view point of leaching from FP and mobility within the hydrogeological environment. At the present time, Sr-90 concentrations in the groundwater at the "Red Forest" site exceed safety limits by 2 - 3 times. Concentrations in other portions of the Ch.NPP are poorly defined.

Available data on the state of the radioactive waste burial sites were obtained by one-time surveys. Ground-water monitoring in the zone of burial sites is insufficient. Sandy soils in the Ch.NPP zone have, in general, low sorption capacity. Presence of organic material in the burial sites favors enhanced actinide (e.g., U and Pu) migration.

Hydrogeological conditions in the zone of burial sites are seriously influenced by artificial factors: drainage systems of the Ch.NPP, waste-water disposal facilities, the cooling pond, etc.

According to conservative projections into the near future (e.g., 10 to 50 years), release of considerable amounts of Sr-90 is possible from disposal site "Building-Base" into the drainage systems of the Ch.NPP, as well as Sr-90 releases of approximately $n \cdot 0.1$ to $n \cdot 1.0$ Ci/year into the Pripyat River from the disposal sites "Oil-Base", "Pripyat", and "Sandy Plateau".

The main uncertainties when assessing and predicting the impact of the radioactive waste burial sites on the hydrogeological environment at Chernobyl are the following:

- Most of the STRWL at present time is uncharacterized. Important data on the location of individual burial sites, amounts and characteristics of the stored radioactive wastes and conditions of contact with groundwater are lacking.
- The mechanisms and parameters governing radionuclide leaching from 100-200 micrometer diameter FP that form much of the contamination of the environment in the Ch.NPP zone are poorly studied, especially under field conditions.

- Sorption properties of sediments are poorly constrained.
- Reliable estimates of ground-water flow velocities in the zone of burial sites are missing.
- Considerable uncertainties are associated with artificial factors to be accounted for in long-term predictions (e.g., mitigative measures, cessation of functioning of Ch.NPP, and construction of "Sarcophagus-2").

Introduction of more clarity into the hydrogeological predictions corresponding to field observations and experiments are necessary. It is advisable to develop a special purpose experimental site to study radionuclide migration from the radioactive waste burial sites under field conditions. Future efforts to understand the hydrogeological setting and contaminant migration surrounding the Chernobyl site should focus on addressing these uncertainties.

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Table 1. Characteristic of the STRWL in the zone immediately adjacent to the CH.NPP (special Enterprise "Kompleks", 1990).

N	Name	Area *10[3] m[2]	Volume of RW m[3]	Amount of activity, *10[3] Ci	Composition of Stored RW
1.	Red Forest	400	5*10[5]	13	Vegetation, soil
2.	Building- Base	1210	8.5*10[4]	31	Vegetation, soil, scrap metal
3.	Yanov	1280	3*10[4]	1	Vegetation, scrap metal, building materials
4.	Pripyat	300	1.6*10[4]	0.7	Scrap metal, domestic wastes
5.	Oil-Base	420	5*10[3]	0.12	Vegetation, soil
6.	Sandy Plateau	880	1*10[5]	5	Soil

Table 2. Chemical composition of ground water from the "Red Forest" site (Kopeykin, Azizov, 1991)

pH	Components, mg/l							Minera- lization mg/l
	nSO ₃	sl	SO ₄	sA	mg	Na	k	
6.7	36.6	7.0	3.7	22.3	2.5	3.2	1.5	131
7.0	115.9	43.7	72.0	35.4	4.9	10.3	16.1	180

Table 3. Amounts of the major long-lived radionuclides in Sector No 2.1 of the "Red Forest" site (0.96 km²), Ci (Illichev et al., 1992)

N	Source	Cs-137	Sr-90	Pu-239+240	Total
1.	Layer 0-0.05 m	294	182	3	480
2.	Layer 0.05-0.5 m	370	260	3.3	633.3
3.	Burial places	2460	1720	22	4670
	Total	3124	2162	28.3	5783.3

Table 4. Radionuclide concentrations in the groundwater of Sector No. 2.1 of the "Red Forest" site, Ci/I (Il'ichav et al., 1992)

	Sr-90	Cs-137	Pu-239+240
Average	10[-5] - 10[-7]	10[-10]	10[-12] - 10[-11]
Maximum	1.3*10[-6]	4.1 10[-8]	1.3*10[-9]

**Table 5. Physico-chemical species of radionuclides in soil samples from trenches of the "Red Forest" site
[*] - Krivokhataki et al.(1992b); [**] - Il'ichev et al.(1992))**

Form	Cs-137 [*]	Sr-90 [*]	Pu-239+240 [**]
Water-soluble	0.1 - 2	12.1 - 21.5	0.03 - 1.9
Exchangeable	1.4 - 8.6	14.7 - 20.4	0.05 - 5.1
Acid-soluble	10 - 17.9	9.1 - 40.4	3.7 - 5.2

Table 6. Sr-90 Kd values for the sediments in the CH.NPP zone
(Column "Method". L - laboratory, P -field determinations)

Sediment type	Site	Method	Kd, ml/g	Source
sand sandy-loam	Red Forest	L	1.9 - 4.4 4.5 - 10	Olkhovik et al. (1992)
sand loam	Podleany	L	5.3 -12.1 7.9	Olkhovik et al. (1992)
sand	Dam of the cooling-pond	F	about 1	Bugai et al. (1991)
sand	CH.NPP zone	L	<1 - 10	Krivokhatski et al. (1992A)
sand	Dam of the cooling-pond	F	<1.8 - 12	Skalski et al. (1993)
sand	Krasnenski channel	F	12 - 25	Skalski et al. (1993)

Fig.2. Hydrogeologic cross section of the Chernobyl NPP zone. Line of section is shown in Fig.1. (Adapted from Myasnikov et al. (1992)).

Fig 1. STRWL in the Chernobyl NPP zone: 1 - Building-Base, 2 - Red Forest, 3 - Yanov, 4 - Pripyat, 5 - Oil-Base, 6 - Sandy Plateau, 7 - Ch.NPP ground.

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