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RELATION BETWEEN NATURAL AND ANTHROPOGENIC FACTORS IN THE REDISTRIBUTION OF RADIONUCLIDES ON THE 30 KM CHERNOBYL NPP TERRITORY, INCLUDING THE RESULT OF COUNTERMEASURES

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Before accident natural and anthropogenic ecosystems occupied about 90% of 30-km zone area, including 36% of forest ecosystem, ploughed lands - 28%, meadows and bogs - 18%. About 10% of total areas were occupied by ameliorated lands, separate water reservoirs - 2.8% relatively large area.

After 10 years after Chernobyl accident the lands structure was changed: areas of forest territories became larger (up to 12-13%). Areas of territories occupied by different technical constructions, roads were increased too. Modern structure of land-using of 30-km zone given in tabl. 1.

Table 1. Modern land structure of 30-km zone

Type of land	%
1. Forest lands	48.5
- pine	38.6
- leafy	9.9
2. Lands uncovered by forest	33.3
- fired forest - place	3.5
- cut forest	0.3
- bed lands, meadows (recent agricultural lands)	29.5
3. Other forest lands	1.1
4. Bogs, sand	2.6
5. Aqua objects	8.5
- cooling pound	1.2
6. Settlements, roads	6.0
Total:	100.0

Contamination of different objects of 30-km zone territory is very uneven, for instance variation of ^{137}Cs contamination of soil reaches the some thousand times (from 0.1-5 up to 10000 and more Ci/km^2).

According with different assessment, total amount (stock of radionuclides, Ci) of main doze-forming radionuclides, located on the territory of 30-km zone given in tabl.2.

Table 2. Radionuclides' stock in 30-km zone, kCi

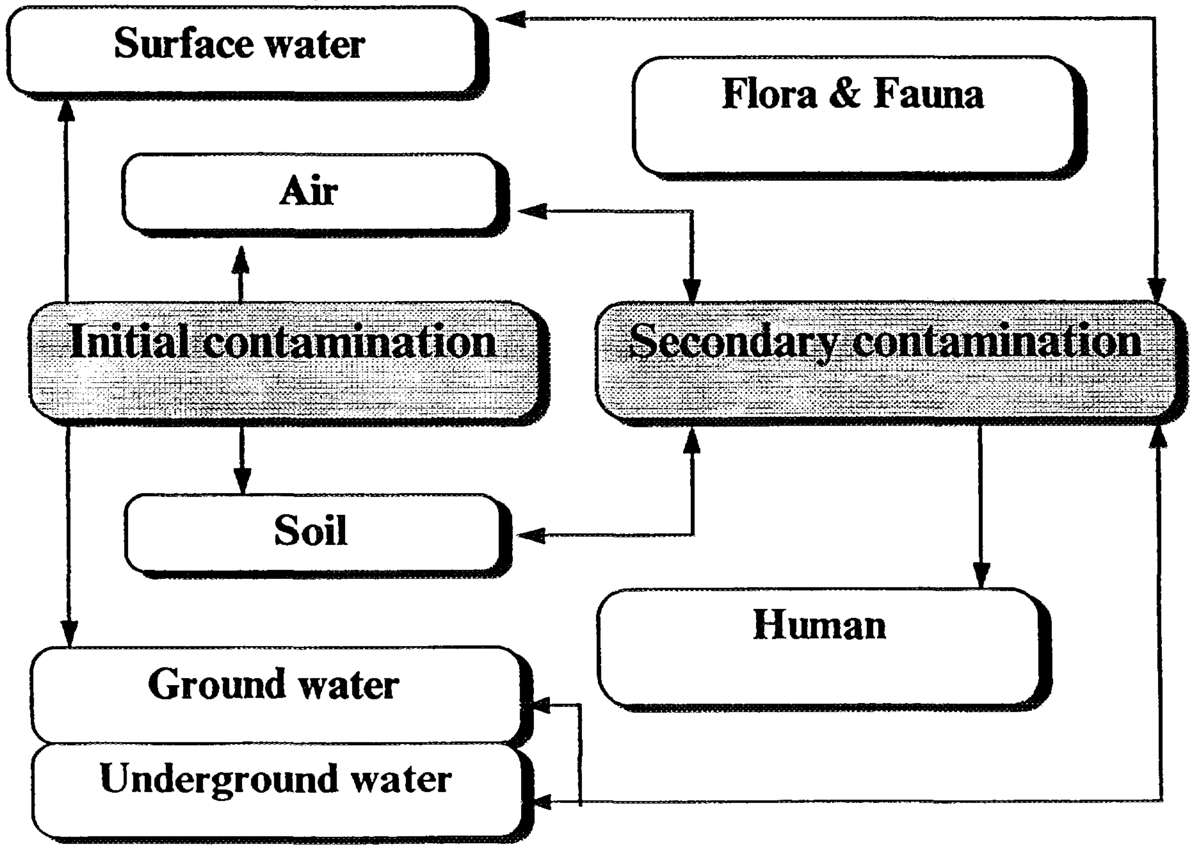
Territory	^{137}Cs	^{90}Sr	$^{239,240}Pu$
5-km zone	33.1	16.9	0.1
30-km zone (without 5-km zone)	93.6	84.4	0.8
including:			
forests	77	60	0.5
former agricultural lands	46	36	0.3
cooling pound of ChNPP	2.4	1.9	0.015
Place of Radioactive Waste Localisation	210	163	1.5

Radioactive contamination, fell down on a surface under natural and anthropogenic factors re-distributed in environments by different ways.

There are five type of migration, according with main factors, determining of migration of radionuclides on the territory:

- Wind (air) migration
- Biogenic migration
- Soil migration
- Water migration
  - * with surface water
  - * with underground water
- Anthropogenic migration

Principal scheme of migration processes is presented on a Fig .1.



Migration and re-distribution of radionuclides by air path-way

Initial contamination of territory was formed through air-path. Later the secondary resuspension (in significant amount) was important in central, high contaminated part of zone and it was caused by wind rising up of soil particles. Soil is a sources of secondary air contamination that is confirmed by relative similarity of radionuclides content of soil and air (table 3)

Table 3.

Relative contamination of soil and air in 1993 (%)

	Soil	Air
^{90}Sr	27	16.7
^{106}Ru	0.4	1.5
^{134}Cs	2.6	3.1
^{137}Cs	46	61
^{144}Ce	1.4	1.2
^{238}Pu	0.2	0.13
$^{239,240}Pu$	0.4	0.28
^{241}Pu	22	15.9
^{241}Am	0.3	0.24
	100	100

Values of resuspension factor in June of 1986 on a territory of 30-km zone were about $(0.5–2)\times10^{-8}$ (Bq/m^3)/(Bq/m^2), that was significant less that was expected (10^{-5}). That is can be explained by following: radioactive contamination of territory was presented mainly as 'heavy' fuel particles, and subsequent gravimetric separation caused accelerative penetration of particles to deeper soil layers (that decreased resuspension factor).

Ten years after accident main part of contaminated area has become turfed, some part of radionuclides penetrated to deeper soil layers or had covered by forest litter or grass mat. It decreased resuspension factor, and now contamination of air is forming by small-dispersed aerosol fraction (less 3-7 μm).

Although the 30-km zone territory is characterised by presence of light sandy and sandy-loam soils, which contents less than 15% soil aggregates, stabled to deflation. However in present time secondary wind resuspension has as a rule restricted, local character (not more than tens and thousands metres) and very low parameters. In 1990 about 5×10^{-5} – 5×10^{-3}% of total contamination stock were risen up and resuspended monthly for a long distance.

Naturally concentration of aerosol increases remarkably during so-named 'dust-storm' and forest fire in 30-km zone. However these are not determine radioactive condition of surface air layer and in present time contamination of air is less than control limit level in 100-1000 times.

Biogenic migration of radionuclides

Flux of radionuclides through chain "soil-plant" is not so significant factor of re-distribution of radionuclides on the territory of 30-km exclusion zone. At the first that is because quantitative characteristics of radionuclides uptake by plants are very low (table 4). Only thousands part of total territory contamination can be drawn into biochemical circle. At the second, part radionuclides which was uptaken by plants as usual (if territory not in agricultural practice) after returned to soil after plants dying off.

Table 4.

Relative fluxes of ^{137}Cs and ^{90}Sr in agriculture ecosystem of Chernobyl 30-km zone with soil contamination density equivalent to 1 kBq/m²

	Mean Tf		Flux, Bq/m²	
	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr
Winter wheat	1.24±0.3	3.26±1.1	0.21	0.55
Winter rye	1.85±0.4	3.78±1.1	0.15	0.30
Barley	0.37±0.1	0.94±0.3	0.05	0.13
Oats	0.32±0.2	0.63±0.14	0.03	0.05
Corn	0.16±0.1	2.5±0.7	0.05	0.75
Rape	11±4	34±22	1.32	4.1
Lupine	6.4±2.3	4.27±2.12	0.71	0.46
Potatoes	0.22±0.02	0.34±0.12	0.15	0.24
Natural grass	3.7±1.9	10.6±1.5	0.37	1.06
Milk products	0.89±0.05	0.03±0.01	0.07	0.002
Meat	0.5±0.2	0.06±0.02	0.35	0.04

Moreover, some biocenoses have properties to accumulate radionuclides inside local landscapes. At the first that is forest ecosystems, land impressions without water flow. According to calculations less than hundredth part of percents released from forest ecosystem.

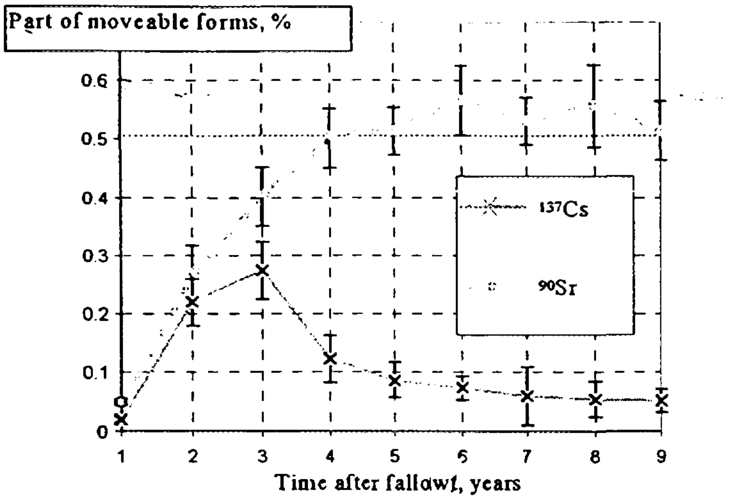
Soil migration of radionuclides

According with landscape assessment, about 40-45% of radioactive fallout located on territory of 30-km exclusion zone concentrated in such elements of landscapes were no possibilities with surface release of radionuclides. On these territories soil migration of radionuclides can take part with infiltrate water only.

During time the intensity of radionuclides infiltration through soil profile changed and was conditioned by increasing of moveable form content.

Concentration of moveable forms of radionuclides in soil is a result of two natural processes with different directions: release of radionuclides from fuel matrix and sorption by soil's minerals.

Typical dynamic of moveable form content in 10-cm layer of soil 30-km zone presented in fig.2.



According with results of lizimetrical observation no more that 1-2% of total radioactivity of 10-cm layer of undisturbed soil taking out with lizimetric water. Many-years dynamic of radionuclides (^{137}Cs and ^{90}Sr) in lizimetrical water shows well relation with content of moveable forms radionuclides in soil.

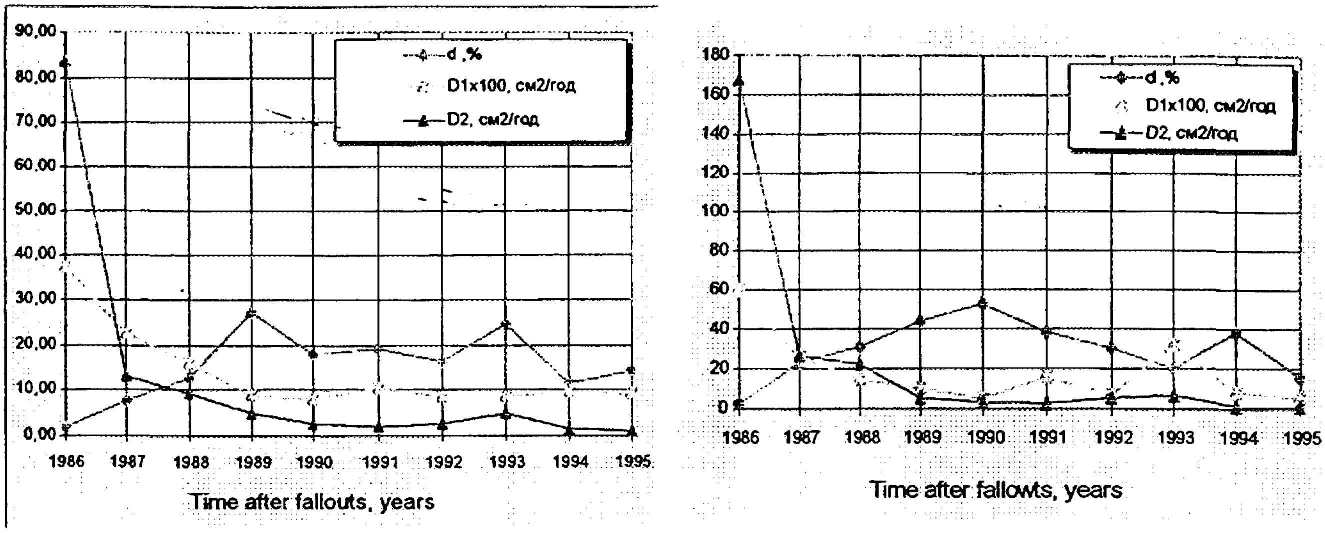
Parameters of vertical migration of radionuclides are often evaluated using a two-component quasidiffusion model of temporary change of radionuclides concentration in soil layers. According with the model the process of vertical redistribution of radionuclides on soil profile is a superposition of redistribution processes of two component of fallout: the radionuclides in composition of 'hot' particles and in water-soluble forms (so-named 'slow' and 'fast', respectively):

$$C(x,t) = C_0 \cdot \left(\frac{1-d}{\sqrt{\pi D_1 \cdot t}} e^{-\frac{x^2}{4D_1 \cdot t}} + \frac{d}{\sqrt{\pi D_2 \cdot t}} e^{-\frac{x^2}{4D_2 \cdot t}} \right)$$

The temporary change of quasidiffusion coefficients D_1 and D_2 (for soddy-podzol soil: D_1 changes from 0.08 to 0.37 cm²/year, D2 - from 1 to 84 cm²/year, for peaty soil: D_1 - from 0.05 to 0.60 cm²/year, D_2 - from 1 to 167 cm²/year) can be explained that an equilibrium of physico-chemical forms of the radionuclides and their stable analogies has not reached in soil. Any specific features of change of the model parameters (depending on soil type) are not observed.

The differences of ratio of 'fast' component depending on soil type have been found out: soddy-podzol soil - D_2 changes from 2 to 27%, for peaty soil - from 3 to 53%. It testifies that leaching of radionuclides from matrix of fuel particles is more intensive in peaty soil, than in soddy-podzol one.

On the pic. 3 many-years dynamic of migration parameters are presented.



a) soddy-podzol soil; b) peat-bog soil;

Picture 3. Dynamic of migration parameters for main type of soil in condition of 30-km zone

Water migration of radionuclides

Horizontal water migration

Water-erosion processes lead to forming of liquid and solid flowing from upper landscape elements. As a rule these flowings are negligible and depend on steepness of slope. The maximum volume of the flowing and intensity of carrying out of small soil fractions take place in February - May, i.e. due to melted water and rain, before forming of grass vegetation. According with different assessment the carrying out of ^{137}Cs with liquid and solid flowing varies from 0.05-0.005% per year.

As well as territories, from which water stock collects, bottom sediments of reservoirs are sources of radionuclides for water. The stocks of radionuclides in bottom sediments of cooling pool of ChNPP and Kievsky reservoir are presented in tabl. 5.

Table 5.

Stocks of some radionuclides in bottom sediments and on waterplate of main reservoirs, Ci

Reservoirs	Square, km^2	^{137}Cs	^{90}Sr	$^{238,239,240}Pu$
Kievsky reservoir (bottom sediments)	922	2600	700	
Cooling pool (bottom sediments)	22.9	4600	770	21
Krasnyansky starik (waterplate)	23.4	7000	4300	175
Benevsky starik (waterplate)	10	375	354	18

Leaching rate of ^{90}Sr from bottom sediments of cooling pool is estimated as 45 Ci/year or less 1 % from total stock. Carrying out of ^{137}Cs and ^{90}Sr with river Pripyat in Kievsky reservoir is shown in tabl. 6. The high values for ^{90}Sr in 1991 are determined by ice jam and flooding of the waterplate in January-February 1991. As result an additional release of ^{90}Sr reached 90 Ci.

Table 6.

Carrying out of ^{137}Cs and ^{90}Sr in Kievsky reservoir with river Pripyat in 1986-1993

Year	Average outlay of water during year, m³/sec	Carrying out, Ci	
		^{137}Cs	^{90}Sr
1986	302	1785	746
1987	246	344	280
1988	411	256	506
1989	392	174	241
1990	409	125	273
1991	442	78	389
1992	295	52	112
1993	597	103	426

Radiation state of underground water in places of temporary localisation of radioactive waste as well as dam of cooling pool of ChNPP causes great trouble. Concentrations of ^{90}Sr are more higher there, than in river Pripyat (tabl.7).

Table 7

^{90}Sr concentration in ground water, pCi/l

Place	November 1992	November 1993
"Red Forest", Strojbasa	19-1200	530-4000
"Red Forest", Yanov	5-32	15-88
Dam of cooling pool	47-380	220-500

Thus the water way of radionuclides migration and redistribution is one of main.

Conclusion

To solve problems of decreasing and liquidation of Chernobyll accident subsequent assessment of intensity of natural processes (wind, rain, accumulation properties and migration factors of soil, chemical and nuclear-physical characteristics of radionuclides) is important criteria of action variants, including assessment of engineering measures efficiency. On a base of comparison efficiency and availability of planning measures evaluates expedient intervention levels too natural processes. In this direction the experience of liquidation of ChNPP accident subsequences gives some practical lessons which can illustrate necessity detail assess and analyse of future results from point of wiev loss and acquisition ("cost-benefit"). Ecological and economical insolvency of some countermeasures of first period (1.5-2 years after accident) was evinced clearly.

There are large-scale and expensive countermeasures of marked period:

Dust-suppression in forest and agricultural lands with using of different artificial polymers, "MM-1", waste of chemical (latex) manufacturing and paper production was not effective measures which did not change radioecologycal situation on a large squares but spent a lot of financial and human expenses.

Building of dams and dikes with ceolite in small rives (132 stick) decreased concentration of radionuclides in water on 3%. But as negative result after increasing of underground water levels 2000 hectares of foorestand was death. There are 120 dike were destroyed after flood in 1987.

"Burring" of "red forest" was done on a square 600 he to decontamination of territory, decreasing external irradiation and to prevent forest fire and distribution of radioonuclides out of 30-km zone. As a result, radionuclides contented in forest litter, were removed to level of underground water and have now large moveability in comparison with initial location.

In compare different ways of radionuclide migration in 30-km zone that is possible to mark following:

- initial radionuclide distribution on a territory of 30-km zone caused in principal by natural processes, landscape and geophysical properties of territory and character of fallout.

- secondary anthropogenic redistribution (flux) of radionuclides was connected significantly with attempts of territory decontamination which lead to change of radionuclide localisation, concentration of radionuclides in different places (about 380 kCi)

- there are more then 600 kCi of long-life radionuclides covered of 30-km zone territory (240 kCi falled out on a surface of soil and reservoirs), which will be subjected by physico-chemical influence, that lead to redistribution and migration through environments

- intensive stage of radionuclide redistribution in natural (environmental) objects are finishing and now processes which speed compared to half-life period of radionucllides are going.