

CHARACTERISTICS OF THE PROCESS OF RESTORATION OF SOIL AND VEGETATION OF THE SEMIPALATYNSK POLYGON AFTER THE DESTROYED INFRASTRUCTURE OBJECTS AS A RESULT OF NUCLEAR EXPLOSIONS IN 1949-1989

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Infrastructure objects were also exposed to radiation pollution during nuclear explosions: buildings, roads, power lines, etc.

To study the process of restoration of soils and vegetation at man-made objects, a military-technical structure was chosen at the Experimental Field experimental site. It is covered with soil and rises one and a half meters above the surface of a flat inter-hill plain. Soil slopes up to 300 are fixed by plants. The soil has not been for PED. The soil is slightly affected by soil formation. The exposure dose rate (PED) is 150 $\mu\text{R}/\text{H}$. Under these radioecological conditions, a sparse group of plants is for PED from *Heteropappus altaicus*, *Kochia siversiana*, *Artemisia marshalliana*, *A. scoparia* with a predominance of *Ephedra distachya*.

The control site was chosen on the dump of the "Trotyl Lake" funnel, for PED as a result of a simulated explosion of the TNT equivalent of an atomic bomb, as a result of which deluvial-proluvial deposits of sandy loam texture were thrown onto the day surface. They are heavily rubbled and contain large fragments of bedrock. The soil is not for PED, the soil is not differentiated into horizons. The PED is 10-14 $\mu\text{R}/\text{H}$. At the bottom of the funnel, a lake with a diameter of 180-200 meters and a depth of 70-80 cm was for PED. The sides of the funnel are vertical, not developed by plants. Sparse plant groups of *Artemisia marchalliana*, *Gypsophila trihotoma*, and *Tripolium vulgare* are for PED along the tops of the dumps with a predominance of *Ephedra distachya*. The data of gamma spectrometric analysis of the aerial parts of plants, plant roots and soils are shown in Table 1.

In this technogenic ecosystem, an increased content of beta-emitters in the roots of plants 4 800 Bq/kg (on control – 2 690 Bq/kg), in the aerial parts of plants – 5 000 Bq/kg (on control – 2 690 Bq/kg) was revealed. The content of other technogenic radionuclides is insignificant.

On a leveled area of a gentle slope to a sor depression of an inclined denudation plain, a section disturbed by engineering and technical communications was studied. Soils - solonets meadow-desert-steppe solonchak heavy loamy anthropogenically disturbed. The PED ranges from 150 to 280 $\mu\text{R}/\text{H}$.

As a result of the leveling of the soil surface, the suprasolonetzic horizon (0-10 cm) was disturbed. Within this layer, horizons are for PED with features characteristic of the suprasolonetzic horizon of solonchaks. Soil restoration is taking place.

Under these radioecological conditions, groups for PED by the lichen *Parmelia vagans* with the participation of the subshrub *Camphorosma monspeliaca*.

The control site was selected on an area identical in relief, microrelief and soils. Disturbances in the soil are currently expressed in a weak form. They appear within the upper 3 cm layer of meadow-desert-steppe solonetz. The soil is actively recovering. The PED is 18 $\mu\text{R}/\text{H}$. Vegetation, as well as in the contaminated area, is represented by a group dominated by *Parmelia vagans* and *Camphorosma monspeliaca*.

The data of gamma spectrometric analysis of the aboveground parts of plants and soils are shown in Table 1.

In this disturbed ecosystem, a high content of Cs^{137} was revealed: in the upper 0-10 cm soil layer it reaches 14 470 Bq/kg (in control - 75 Bq/kg), in *Parmelia vagans* – 54 000 Bq/kg (in control - 710 Bq/kg). A significant content of beta activity was noted: in soils - 42 p/cm² (in control - 2 p/cm²), in plants – 12 500 Bq/kg (in control – 4 200 Bq/kg). The content of other technogenic radionuclides is insignificant.

In order to reveal the impact of radiation pollution on the formation of xerohalophytic ecosystems distributed along power lines, sites on polluted (PED 120-130 $\mu\text{R}/\text{H}$) and control (17-18 $\mu\text{R}/\text{H}$) habitats were studied. The relief is represented by an inclined denudation-accumulative plain. The polluted area is located on a flattened slightly disturbed gentle slope to the Jamantuzsor depression. The control site is located 400 m to the south and down the slope. Soils – solonetz meadow-desert-steppe weakly disturbed solonchakous.

Under these radioecological conditions, communities of *Camphorosma monspeliaca*+*Atriplex cana* are for PED in the contaminated area and communities of *Camphorosma monspeliaca*+*Atriplex cana* in the control area. The projective soil cover by plants in the polluted area reaches 30-40% (in the control area - 40-50%). Ground cover is absent.

In slightly disturbed soils from the surface, the process of their restoration takes place. The studied communities are at the stage of restoration of vegetation in accordance with the radioecological conditions of the habitats.

The results of the analysis of the composition of radionuclides, integral measurements of alpha and beta activity of soil samples, roots and aboveground parts of plants are shown in Table 1.

A significant content of Cs^{137} was found in the contaminated area. In the soil layer of 0-9 cm, the PED reaches 5 227 Bq/kg (41 Bq/kg in the control). Up to 2 440 Bq/kg is accumulated in plant roots (320 Bq/kg in the control), 2 770 Bq/kg in the aerial part of plants (420 Bq/kg in the control). The content of the beta-emitter in the soil reaches 22 p/cm² (on the control - 2 p/cm²). 31 000 Bq/kg is accumulated in the roots of plants (in the control - 5 800 Bq/kg), in the aerial part - 10 600 Bq/kg (in the control - <800 Bq/kg).

In the floodplains of the streams of the Degelen low mountains, the restoration of an anthropogenically disturbed meadow ecosystem was studied. After nuclear explosions in adits, aquifers were opened. Radioactive streams formed. In 1996-1999 the adits were demilitarized. It contributed to the improvement of the radioecological situation: in many areas, the level of exposure dose significantly decreased. But in some areas (portal and estuarine sites, access roads, floodplains of streams), new technogenic habitats have been formed. After the mouths of the galleries were closed, the moisture regime in the floodplain of the streams changed dramatically.

The polluted site is located on the micro-elevation of the central part of the floodplain of the Uzunbulak stream. Soils - meadow of surface moistening carbonate stepping loamy strong. The exposure dose rate is 190-200 μ R/H. Under these radioecological conditions, communities of *Galatella biflora* + *Potentilla virgate* + *Elytrigia repens* + *Calamagrostis epigeios* are formed. Projective cover reaches 60-70%, ground cover 10-15%. Vegetation is represented by the stage of restoration of meadow communities.

The control site is located on the leveled section of the floodplain of the Karabulak stream. Soils - meadow drying light loamy carbonate. The exposure dose rate is 19-20 μ R/H. Under these radioecological conditions, communities of *Potentilla virgata* + *Galatella biflora* + *Elytrigia repens* + *Leymus angustus* are formed. Projective soil cover by plants reaches 80-90%, ground cover - 5-10%. Vegetation is represented by the stage of restoration of meadow communities.

The results of gamma spectrometric analysis of the aerial parts, plant roots and soils are shown in Table 1. A high content of beta-emitters was found in the disturbed ecosystem formed on the polluted site: in soils (in the layer of 0-16 cm) - 16 p/cm² (on control - 2 p/cm²), in plant roots - 4 500 000 Bq/kg (at control - 900 Bq/kg), in the aerial parts of plants - 3 400 000 Bq/kg (in control - 7 000 Bq/kg). The content of other technogenic radionuclides is insignificant.

After the closure of adits and the cessation of water intrusion (of them), the moisture regime in the floodplains of the streams changed. Meadow soils dry out (as in the polluted area) and become steppe (as in the control area). In the composition of communities, changes are taking place along the line of xerophytization of vegetation. The main factor of the radioecological conditions is the humidification regime.

The polluted site and control site were set up at fortification ruins area of «Experimental field» test site for detailed study of the process of vegetation restoration of the ruins area.

Polluted site is located on a wide flat plain between hills. Part of the plain disturbed by military and technical construction. Ruins of building in the form of flat hill of 100-120 cm height, formed mainly of bricks and concrete debris. PED: 150-160 μ R/H; Soil: disturbed by construction material at the initial stage of light chestnut soil formation;

The soil cover was strongly disturbed even at the period of building construction and then was buried under ruins of building. Soil was destroyed completely. At present the process of soil formation starts at a quite different substratum. Its direction will be determined by the complex of biological and climatic conditions. At places where among constructive debris exist sites filled with fine earth, initial features typical for zonal light chestnut soils appear. Thus, soil at the polluted site is completely destroyed and buried under the constructive debris, where the initial process of soil formation occurs.

The control site it is located on a wide flat aluvial-proluvial plain. A part of the plain disturbed by military and technical construction. Ruins of building and constructive debris (bricks, concrete, slag) in the form of flat hill of nearly 150 cm height. PED: 14-15 μ R/H; Soil: ruined construction material, at initial stage of light chestnut soil formation;

The initial soil is greatly disturbed and buried under building remains and construction debris at the control site. The initial stage of soil formation proceeds on a new anthropogenic substratum.

Aggregations with predominance of *Stipa sareptana*, *Artemisia marschalliana*, *A. scoparia*, *Festuca valesiaca* develop at the building ruins area with PED of gamma irradiation of 150-160 μ R/H. Aggregations with predominance of *Stipa sareptana*, *Artemisia schrenkiana*, *A. dracunculus*, *A. marschalliana*, *Festuca valesiaca* develop at the control site with PED of gamma irradiation of 14-15 μ R/H.

Direct comparison of the aggregation study results at the control and polluted sites revealed that:

- 1) total coverage in the aggregation at the polluted site is 10-20%, at the control site - 10-15%;
- 2) soil surface cover at the polluted site is 1-2 %, it is absent at the control site;
- 3) coverage of soil by plants at the polluted site reaches 10-20%, at the control site -10-15 %;
- 4) vegetation is represented by underdeveloped plant aggregation at the polluted and control sites, reproduction of dominating plants is seminal.

Destroyed building material is substratum for soil formation at the polluted site. It is significantly polluted. Content of Am^{241} is 2269 Bq/kg, Cs^{137} - 5379 Bq/kg, $Eu^{152-154}$ - 1031 Bq/kg. Content of the rest artificial and natural radionuclides is insignificant. The site is also significantly polluted by α -integral activity (α -integral activity is 23 particles from one sq. cm per minute). At the control site it is necessary to mark accumulation of Cs^{137} - 26 Bq/kg. Content of the rest technogenic radionuclides is insignificant. α -integral activity at the control site exceeds permissible limits by 8 times (α -integral activity is 16 particles from one sq. cm per minute).

The polluted site and control site were set up at the area of «Experimental field» test site for detailed study of the process of vegetation restoration of the road area.

The polluted site it is located on a wide flat plain between hills. Part of a plain adjoining to the rut of ground road. The road rut is cut in to the depth of 15-20 cm from the surface level. Grader traces are noticed along the road. PED: 700-900 μ R/H; Soil: light chestnut anthropogenic disturbed and planned.

At the polluted site road soil digression occurs at high radiation background. The rut of one of the main ground roads is cut in to the depth of 15-20 cm from level of soil surface. Deeper this level soil horizons are also destroyed. This is revealed in strong soil mass compaction, destroy of soil structure and deterioration of water-physical and physical and chemical characteristics. I.e. soil just in the rut is disturbed to a great extend. On the sites adjoining to the rut disturbance has the lesser strong character. The initial soil surface along the road was smoothed by grading, fine earth and frame material were thrown to the rut edge from the road rut. As a result soil horizons are often cut from the soil along the road and often are blocked by more coarse material thrown from road rut and gathered by grader. The layer of high disturbance here makes nearly 6 cm. I.e. according to «Scientific and methodical directions on soil monitoring of the Republic of Kazakhstan» (1994) the disturbance has medium character. The disturbed horizons are restored after systematic stop of road utilisation. The typical colour and structure appear in them. The level of rehabilitation doesn't exceed the average one.

The control site it is located on the wide flat plain between hills. Part of the plain adjoining to the rut of ground road. The road rut is cut in to the depth of nearly 15 cm. The traces of grading are noticed along the road. PED: 15-18 μ R/H; Soil: light chestnut of anthropogenic disturbed and planned.

At the control site the same as at the polluted site degree of soil disturbance was revealed. Restoration of soil horizons proceeds under PED of gamma irradiation of 15-18 μ R/H.

Coenosis with predominance of *Artemisia marschalliana*, *A. frigida*, *Stipa sareptana* develops at the polluted site adjoining to gauge of country road. Coenosis with predominance of *Artemisia marschalliana*, *A. austriaca*, *Stipa sareptana* develops at the control site under PED of gamma irradiation of 15-18 μ R/H.

Direct comparison of the investigation results of the coenosis at the polluted and control sites revealed that:

- 1) total coverage in the procoenosis at the polluted site is 40-60%, at the control site - 35-60%;
- 2) soil surface cover is absent in the coenosis;
- 3) coverage soil by plants at the polluted site is 40-60 %, at the control site - 35-60%;
- 4) vegetation is represented by stage of restoration of communities at the area adjoining to country road at the polluted and control sites, reproduction of predominating plants is seminal.

Cs^{137} dominates among technogenic radionuclides at the polluted site. Its content in soil layer of 0-10 cm is 18 516 Bq/kg, at the control site - 44 Bq/kg. There is significant amount of $Eu^{152-154}$ - 6108 Bq/kg (at the control site - 4 Bq/kg), Am^{241} - 1830 Bq/kg (at the control site - 104 Bq/kg), Co^{60} - 269 Bq/kg (at the control site - <1 Bq/kg). Content of α -integral exceed by far permissible limit at the polluted site. It is 22 particles from 1 sq. cm per minute (at the control site - 15 particles from 1 sq. cm per minute). Content of β -integral reaches 341 particles from 1 sq. cm per minute (at the control site - 2 particles from 1 sq. cm per minute).

The polluted site and control site were set up at the area of «Experimental field» test site for detailed study of the process of restoration of the vegetation disturbed by fortification construction.

It is located on a wide flat plain between hills. Part of plain disturbed by military technical construction. An embankment up to 2 m around facility construction. A top smoothed part of the embankment at the transition to the eastern slope. PED: 250-400 μ R/H; Soil: light chestnut weakly formed.

At present soils on sprinkles around facility construction are formed over again. The initial soils were greatly disturbed at object construction and crossed with soil-ground layer of up to 2 m taken, probably, from the surrounding territory. Ground has light loamy composition of fine earth rock wasted to an average degree. The top parts of the ground are marked by the appearance of features of differentiation for horizons, change of colour, structuralization, high saturation of soil-ground mass with plant roots. The disturbance of initial soils at the polluted site was very strong. They were artificially blocked by powerful soil-ground layer where light chestnut weakly formed soil is developed at present. The soil formation proceeds at high pollution level.

The control site it is located on a wide flat plain between hills. Part of plain disturbed by military technical construction. Embankment of about 2 m around the facility construction. The eastern slope of embankment. PED: 16-18 $\mu\text{R}/\text{H}$; Soil: light chestnut weakly formed.

The cycle of soil development at the control site in general is analogous to that of soils at the polluted site but proceeds in conditions of normal radiation background.

Aggregations with predominance of *Stipa sareptana* and *Festuca valesiaca* develop on the embankment surrounding measuring installation at the areas with PED of gamma irradiation of 250-400 $\mu\text{R}/\text{H}$ and the areas with PED of gamma irradiation of 16-18 $\mu\text{R}/\text{H}$.

Direct comparison of the investigation results of the aggregations at the polluted and control sites revealed that:

- 1) total coverage in the aggregation at the polluted site reaches 30-45%, at the control site - 10-15%;
- 2) soil surface cover is 20-30 % at the polluted site, at the control site it is absent;
- 3) coverage of soil by plants is 10-15 % at the polluted site, at the control site - 10-15%;
- 4) vegetation is represented by underdeveloped aggregations of plants at the polluted and control sites, reproduction of predominating plants is seminal.

Cs^{137} dominates among technogenic radionuclides at the polluted site in soil layer of 0-10 cm. Its content is 890 Bq/kg (at the control site - 13 Bq/kg). Content of other technogenic radionuclides at the polluted site is Am^{241} - 527 Bq/kg (at the control site - 16 Bq/kg), $Eu^{152-154}$ - 252 Bq/kg (at the control site - <3 Bq/kg).

Content of α -integral activity is 8 particles from sq. cm per minute at the polluted site in soil layer of 0-10 cm, at the control site - 13 Bq/kg. Content of β -integral activity is 8 particles from sq. cm per minute at the polluted site, at the control site - 2 particles from sq. cm per minute.

Three observation site (1, 2, 3) were set up to reveal peculiarities of vegetation syngenetic succession in extreme conditions at the dumps of «Atomic lake» under PED of gamma irradiation of 1100-1700 $\mu\text{R}/\text{H}$.

Observation site #1. It is located in the low part of the internal slope of explosion crater. The dump is presented by debris material of destroyed native rocks. PED 1400-1700 $\mu\text{R}/\text{H}$. Ground sandy loamy rock waste-stony-debris. A ground sample was taken for radiation analysis from the layer of 0-10 cm of the dump's surface.

Observation site #2. It is located in the middle part of the external slope of crater dump of «Atomic Lake». The dump is presented by stony-blocky with fine earth material of destroyed native rocks. PED 1400 $\mu\text{R}/\text{H}$. Ground sandy loamy-rock waste-stony-debris; A ground sample was taken for radiation analysis from the layer of 0-10 cm of the dump surface.

Observation site #3. It is located on the top of «Atomic Lake» crater slope. Inclined flat site with large rock debris. PED 1100-1400 $\mu\text{R}/\text{H}$. Ground loamy-rock waste-stony-debris. A ground sample was taken for radiation analysis from the layer of 0-10 cm of the dump surface.

As a result of explosion the surface cover in the area of «Atomic Lake» was completely destroyed on large area. Large sink with a dump composed of thrown porous deposits, salined gypsum clays and large debris of thick native rocks was formed at the epicentre of explosion. High radiation background is still preserved near the sink. Sink dump has a complicated relief configuration, steep slopes, weakly fixed by vegetation so water erosion processes are actively happen here during sedimentation fall and snow melting. Soil forming process on the weathered rocks proceeds very slowly. Due to these reasons and the shortness of soil forming period soils are nor formed on the sink dumps. Vegetation settle on the ground very weakly touched by the soil forming processes. This is the most initial stage of soil forming.

Aggregations with predominance of *Atraphaxis frutescens* develop at the lower and middle parts of external slope of the dump. Single individuals of *Atraphaxis frutescens* are marked at the top of the dump.

Direct comparison of investigation results of vegetation at the polluted and control sites revealed that:

- 1) total coverage and coverage of soil by plants at the top of the dump is 3-5 %, soil surface cover does not develop;
- 2) at the middle part of external slope and lower part of internal slope total coverage and coverage of soil by plants is 10-15 %, surface cover does not develop;
- 3) vegetation of the o.p. is primary stage of restoration of communities at technogenic habitats, reproduction of plants is seminal.

Radiation pollution of grounds of the top and slopes of the dumps of «Atomic lake» is high. Co^{60} dominates among technogenic radionuclides at the top of the dump. Its content is 50165 Bq/kg. Besides that, high content of Eu^{152} (8954 Bq/kg), Eu^{154} (4605 Bq/kg) and Am^{241} (858 Bq/kg) is marked here. Content of α -integral activity is 15 particles from sq. cm per minute and β -integral activity is 80 particles from sq. cm per minute. Eu^{152} dominates among technogenic radionuclides in grounds of the middle part of external slope of the dump. Its content is 19003 Bq/kg. High content of Cs^{137} (16570 Bq/kg) and Co^{60} (12257 Bq/kg), Eu^{154} (10100 Bq/kg) and Am^{241} (1888

Bq/kg) is marked here. Content of α -integral activity is 17 particles from sq. cm per minute and β -integral activity is 165 particles from sq. cm per minute. Eu^{152} dominates among technogenic radionuclides in grounds of the lower part of internal slope of the dump. Its content is 13378 Bq/kg. High content of CS^{137} (13287 Bq/kg), Co^{60} (8184 Bq/kg), Eu^{154} (6860 Bq/kg) and Am^{241} (1222 Bq/kg) is marked here. Content of α -integral activity is 17 particles from sq. cm per minute and β -integral activity is 113 particles from sq. cm per minute.

Table 1. Consolidated report of results of computation spectral analysis of disturbed ecosystems

Plant name	Overground part of plant							Roots							Soils														PED μR/H	
	Radionuclides content Bq per kg							Radionuclides content Bq per kg							Depth of sampling	Radionuclides content Bq per kg														
	Am ²⁴¹	Cs ¹³⁷	Co ⁶⁰	Eu ^{152,154}	K ⁴⁰	a	b	Am ²⁴¹	Cs ¹³⁷	Co ⁶⁰	Eu ^{152,154}	K ⁴⁰	a	b		Am ²⁴¹	Cs ¹³⁷	Co ⁶⁰	Eu ^{152,154}	K ⁴⁰	U ²³⁸	Ra ²²⁶	Pb ²¹⁰	Th ²³²	a	b	a*	b*		
Polluted sites															Polluted sites															
<i>Ephedra distachya</i>	59	49	3,3	70	3300	<900	5000	<300	10	<5	79	3900	1700	4800	0-5cm	2355	101	52	1020	828		54		42			28	3	150	
<i>Atriplex cana</i>	<8	2770	<10	<20	3900	<800	10600	<30	2440	<16	<30	3900	1200	31000	0-9cm	41	5397	3	8	549		29		33			28	22		
															10-20cm	<1	186	<1	9	682		41		39			11	2	120-130	
															25-35cm	<1	6	<1	5	566		48		32			11	3		
<i>Potentilla virgata</i>	<300	320	<20	<110	6700	3600	3400000	<300	100	<12	<160	5000	13000	4500000	0-6cm	6	1513	<1	9	1423		68		80			11	8		
															6-16cm	<1	13	<1	<3	1152		61		81			11	8	190-200	
<i>Parmelia vagans</i>	19	54000	<10	<50	1200	2460	125000								0-10cm	8	14470	<1	<3	635		37		30		18	42	150-280		
Control sites															Control sites															
<i>Ephedra distachya</i>	7	40	<4	<8	2800	<800	2400	<10	9	<16	<18	3700	480	2690	0-5cm	58	6	<1	3	717	19	39		34		15	2	10-34		
<i>Atriplex cana</i>	<18	420	<12	<15	2900	<800	4500	<3	320	4,5	<10	2900	<800	5800	0-8cm	3	15	<1	5	526		5		30			6	2		
															10-20cm	<1	6	<1	<1	592		28		29			<1	1	17-18	
															25-35cm	<1	<1	<1	<3	520		34		29			9	<1		
<i>Potentilla virgata</i>	<20	18	<20	<24	4360	2900	7100	<20	<14	<20	<30	4000	10700	900	0-7cm	<1	69	<1	<4	1112		35		52		9	2			
<i>Parmelia vagans</i>	14	710	<8	<12	1100	1700	4200								0-10cm	<1	78	<1	<2	577		35		26		11	2	18		

* Integral activity in particle 1cm²/min