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РЕТРОСПЕКТИВНАЯ ОЦЕНКА И МОДЕЛИРОВАНИЕ РАДИОАКТИВНОГО ЗАГРЯЗНЕНИЯ ТЕРРИТОРИИ РЕСПУБЛИКИ БЕЛАРУСЬ В РЕЗУЛЬТАТЕ КАТАСТРОФЫ НА ЧЕРНОБЫЛЬСКОЙ АЭС

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В исследовании представлены концептуальные подходы по ретроспективной оценке и моделировании радиоактивного загрязнения территории Республики Беларусь в результате катастрофы на Чернобыльской АЭС (ЧАЭС). Работа выполнялась в рамках выполнения задания 3.01 «Исследование влияния ионизирующего излучения в широком диапазоне доз и при вариабельности характеристик излучения на разных уровнях организации живого организма» НИР «Оценить дозовые нагрузки и эффекты ионизирующих излучений в сочетании со стрессом различной природы на биоту в зоне хронического радиационного воздействия», ГПНИ «Природные ресурсы и окружающая среда» подпрограммы «Радиация и биологические системы» на 2021–2025 годы.

В результате выполнения работы был определен радионуклидный состав (для оценки последствий поступления радионуклидов в окружающую среду для биоты) и уровни радиоактивного загрязнения компонентов экосистемы в зоне наблюдения Гомельской, Витебской и Гродненской областей Республики Беларусь. Радиационная обстановка рассматривалась на разных временных этапах: в результате испытания ядерного оружия и после аварийного выброса на ЧАЭС [1; 2].

В настоящее время, по нашим данным, в зоне наблюдения Гомельской, Витебской и Гродненской областей Республики Беларусь радиационная обстановка обусловлена радионуклидами ^{137}Cs и ^{90}Sr. Значительно возрастает миграция ^{90}Sr в почве и по пищевой цепочке в результате деструкции топливных частиц и, как следствие, ^{90}Sr попадает в почвенные растворы, после чего мигрирует вглубь почвы.

Кроме того, в Гомельской обл. происходит накопление ^{241}Am за счет распада ^{241}Pu. Максимальный уровень загрязнения ^{241}Am установится к 2060 г. и превысит $^{239+240}$Pu в 2,7 раза, при этом территории с уровнем загрязнения $^{238+239+240}$Pu + ^{241}Am до 1000 Бк/м^2, возможно, выйдут за пределы 30-километровой зоны.

Полученные результаты по выявлению наиболее значимых радионуклидов в зоне наблюдения Гомельской, Витебской и Гродненской областей Республики Беларусь и определяемые ими уровни радиоактивного загрязнения компонентов экосистемы Беларуси будут использованы для оценки последствий поступления радионуклидов в окружающую среду для биоты и прогнозирования развития радиоэкологической ситуации на рассматриваемых территориях, что важно для практического использования в организациях, принимающих организационные решения. Результаты научных исследований внедрены в учебный процесс в рамках лекционных и практических занятий на факультете мониторинга окружающей среды Международного государственного экологического института им. А. Д. Сахарова Белорусского государственного университета.

Ключевые слова: окружающая среда; радиоактивное загрязнение; топливные частицы; миграция радионуклидов.

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RETROSPECTIVE ASSESSMENT AND MODELING OF RADIOACTIVE CONTAMINATION OF THE TERRITORY OF THE REPUBLIC OF BELARUS AS A RESULT OF THE DISASTER AT THE CHERNOBYL NPP

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The article presents conceptual approaches to retrospective assessment and predictive modeling of radioactive contamination of the territory of the Republic of Belarus as a result of the Chernobyl accident. The work was carried out within the framework of project 3.01 «Investigation of the effect of ionizing radiation in a wide range of doses and with the variability of radiation characteristics at different levels of organization of a living organism», GPNI «Natural resources and the environment» of the subprogram «Radiation and biological systems» for 2021–2025.

We determined the most significant radionuclide composition (for assessing the consequences of the release of radionuclides into the environment for biota) and the levels of radioactive contamination of ecosystem components in the observation zone of the Gomel, Vitebsk and Grodno regions of the Republic of Belarus. The radiation situation was considered at different time stages, namely as a result of atmospheric nuclear weapons testing and after an emergency release at the Chernobyl nuclear power plant [1; 2]. At present time, according to our data, in the observation zone of the Gomel, Vitebsk and Grodno regions of the Republic of Belarus, the radiation situation is caused by ^{137}Cs and ^{90}Sr radionuclides. The migration of ^{90}Sr in the soil and through the food chain significantly increases as a result of the destruction of fuel particles and, as a consequence, ^{90}Sr enters the soil solutions, after which it migrates deep into the soil. In addition, in the Gomel region, ^{241}Am accumulates due to the decay of ^{241}Pu. The maximum contamination level of ^{241}Am will be established by 2060 and will exceed $^{239+240}$Pu by a factor of 2.7, while territories with a contamination level of $^{238+239+240}$Pu + ^{241}Am up to 1000 Bq / m^2 may possibly go outside the 30-km zone. The results of scientific research were introduced into the educational process within the framework of lectures and practical classes at the Faculty of Environmental Monitoring of the International Sakharov Environmental Institute of Belarusian State University.

Keywords: environment; radioactive contamination; fuel particles; migration of radionuclides.

Introduction

The radionuclide composition and the levels of radioactive contamination of ecosystem components of Belarus at different time stages after radionuclide release into the environment mainly determine the priorities in applied radio ecological and radio biological research, the tasks of radiation protection of the population [3]. The paper generalizes the results of long term experimental observations of radionuclide composition dynamics, the levels of radioactive contamination of air and soil as a result of nuclear weapons test and after the Chernobyl NPP emergency release.

Research materials and methods

The main levels of soil radioactive contamination as a result of global fallouts on the territory of the Republic of Belarus were formed in the mid 70's after conducting of intensive nuclear test in the atmosphere before the ratification of the Moscow agreement on the Prohibition of Nuclear Weapons Test (1963–1964) when annual fallout density of plutonium reached maximum figures: 10–15 Бк. In this period, $^{239+240}$Pu concentration in air reached several dozens of μBq/m^3. It led to an increased inhalation intake of transuranic elements into the body of the citizens of Europe and the Republic of Belarus as well, $^{239+240}$Pu level in the body was about 7 Bq by the time of the accident at the Chernobyl NPP [4–6].

The concentration of ^{137}Cs increased from 4.0 μBq/m^3 to 130 μBq/m^3 in the northwest of Belarus in May, 1981. As it concerns $^{239+240}$Pu, the rise was from 57 nBq/m^3 to 2300 nBq/m^3. This strong increase in activity in May was the result of stratospheric fallout from the last 26th China's land-based nuclear test held in October, 1980. Maximum content of $^{239+240}$Pu and ^{137}Cs was observed in the middle of May at 3500 nBq/m^3 and 220 μBq/m^3 correspondingly.

An increase in activity ratio of ^{137}Cs to $^{239+240}$Pu from long term patterns can be noted. The average of this ratio was 63 in 1980 compared to 150 in 1985. Such a difference can be explained that in a nuclear explosion cesium is primarily bound to fine aerosols in the air with the diameter lower 0,1 μm what causes their high volatility. While plutonium can exist in a different, less volatile form consisting of oxides after high temperature annealing [4].

At the beginning of April, 1986, the concentration of radionuclides in surface air according to our experimental data was [6]: ^{137}Cs – 0,36 μBq/m^3, $^{239+240}$Pu – 4,7 nBq/m^3, ^{238}Pu – 0,13 nBq/m^3, ^{90}Sr – 220 nBq/m^3, surface soil contamination: ^{137}Cs – 1900 Bq/m^2, $^{239+240}$Pu – 55 Bq/m^2, ^{238}Pu – 1.5 Bq/m^2, ^{90}Sr – 1200 Bq/m^2. For global fallouts in April, 1986, the ratio in activity of the most significant actinides according to our experimental data was: ^{238}Pu/^{239}Pu/^{240}Pu/^{241}Pu/^{241}Am = 0.043/1,0/0,57/20/0,5 [4].

Radioactive release spread for large distances and contaminated a lot of European territory as a result of the Chernobyl accident. The territory of more than 200000 km^2 was contaminated with radioactive ^{137}Cs more than 0,04 MBq/m^2 [7].

The study of the spatial distribution of radioactive contamination of the European territory shows that the spread of radioactive substances had both a global, and a local, regional character. The atmospheric radioactive fallout was determined by the synoptic situation and meteorological conditions for the period April 26, – May 6, 1986, as it is shown in Fig. 1 [7].

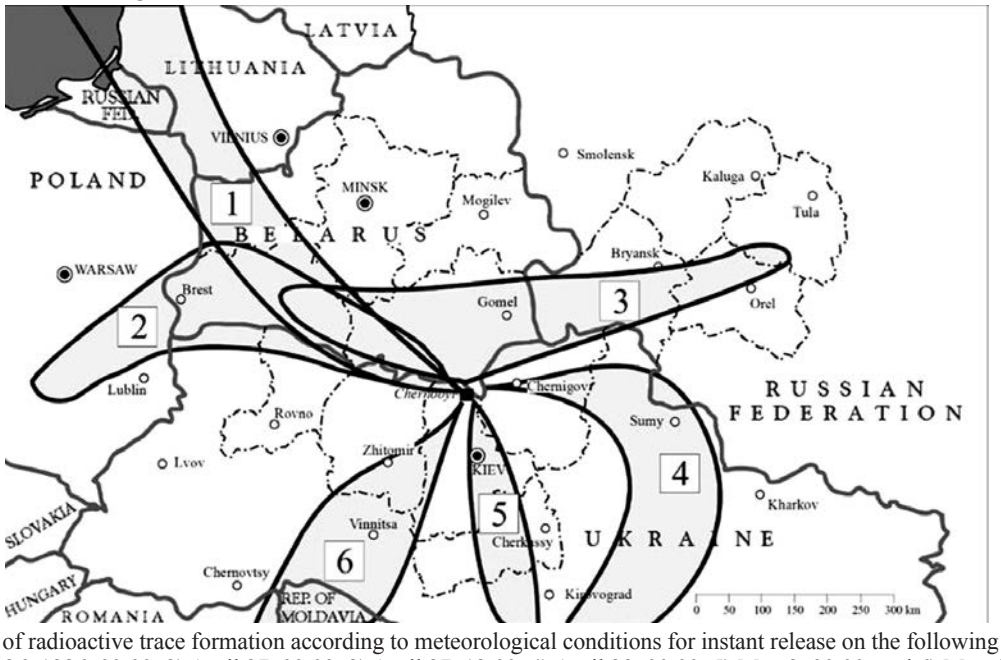

Fig. 1. Scheme of radioactive trace formation according to meteorological conditions for instant release on the following dates and time 1) April 26, 1986, 00:00; 2) April 27, 00:00; 3) April 27, 12:00; 4) April 29, 00:00; 5) May 2, 00:00; and 6) May 4, 12:00

In the dynamics of contamination of the territory of the Republic of Belarus by radionuclides released into the environment as a result of the accident at the Chernobyl NPP, the following stages can be distinguished: «The active stage of the accident or the iodine-neptunium phase»; «The stabilization of radiation condition»; «Cesium-strontium phase»; «Actinide phase».

The forecast of soil radioactive contamination at the defining point Masany, Hoiniki district, Gomel region (12 km north of the Chernobyl NPP IV block) based on the experimental data shown in Fig. 2. A former locality Masany was chosen as the defining point due to the fact that the radioactive contamination covered this area soon after the explosion and the radionuclide composition of soil contamination fully reflected time-aggregated radionuclide composition of an accidental release.

The forecast of radioactive contamination on the example of the defining point Masany allows finding out and describing the main dynamics stages of radioactive situation in the environment after the Chernobyl disaster for up to 1,000 years or more.

Results and discussion

The active stage of the accident or the iodine-neptunium phase. The duration is about a month after the release. At this stage there was more intensive fall out on soil that formed observed levels of surface soil contamination with radionuclides of the Chernobyl origin. Significant changes in isotope ratio ^{238}Pu и $^{239+240}$Pu also occurred here. Activity ratio ^{238}Pu/$^{239+240}$Pu increased from 0.03 to 0.4–0.5, ^{137}Cs/$^{239+240}$Pu from 100 to 105 [4]. At this stage there was more inhalation intake of actinides into the body of the citizens of the Republic of Belarus, the level of «the Chernobyl» $^{238+239+240}$Pu in the body of Gomel region citizens evaluated 15 Bq [6]. The short-lived isotopes, determined radiation situation in the first days after the accident, were in the form of condensing and fuel particles. The condensing particles include radioactive isotopes ^{132}Te, ^{134}Cs, ^{136}Cs, ^{137}Cs, ^{103}Ru and ^{106}Ru. ^{239}Np, ^{95}Zr, ^{95}Nb, ^{140}Ba, ^{140}La, ^{144}Ce, etc., were part of fuel particles. The ratio of these radionuclides is significantly determined by the burn up depth of nuclear fuel at the NPP reactor which determines the amount of isotopes and their ratio in the irradiated fuel [8; 9]. The method of irradiated ^{236}U fuel use as a tracer was specially developed for the determination of a depth burn up and the amount of uranium fuel in the soil after the accident at Chernobyl NPP [10]. It is based on the calculated correlations between uranium isotopes in the core of the RBMK-1000 reactor depending on the depth of fuel burn up and experimental data on the ratio in the samples of radioactive isotope soil and technogenic release of ^{235}U, ^{236}U, ^{238}U. Average fuel burn up is (9.4 ± 0.5) MW*day/kgU [8–10]. Therefore this average value was adopted for work on isotope ratio calculation [11–13].

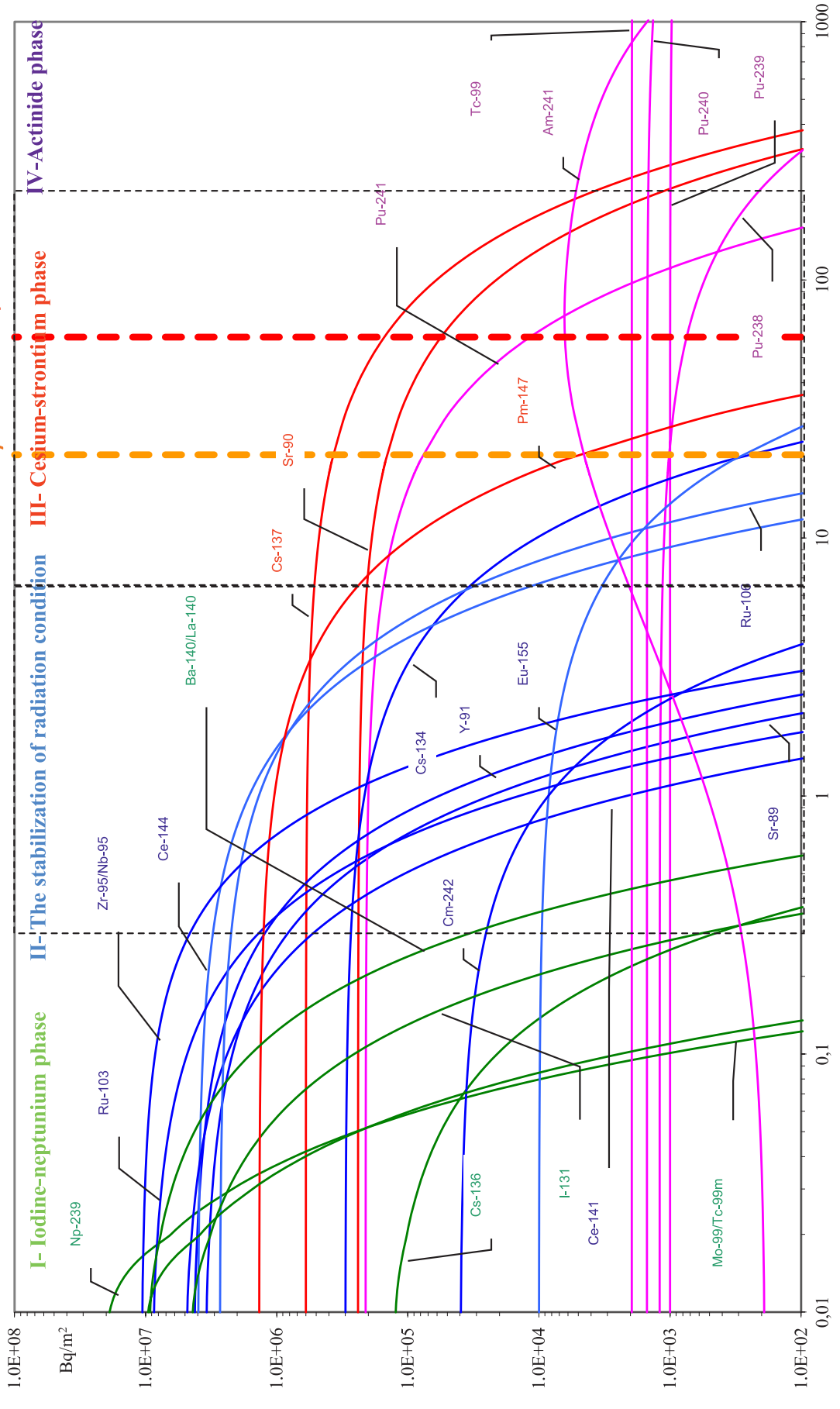

Fig. 2. The forecast of soil radioactive contamination at the defining point Masany based on the experimental data of radionuclide fraction coefficients

When calculation of fallout of radioactive isotopes ^{140}La, ^{140}Ba, ^{95}Zr, ^{97}Zr, ^{95}Nb, ^{156}Eu, ^{239}Np, ^{143}Ce, their ratio to ^{144}Ce was considered as these radionuclides were in the composition of fuel particles [9; 10]. It was also supposed that there wasn't ^{137}Cs c ^{99}Mo and ^{103}Ru, ^{106}Ru radionuclides fractionation as well as the radionuclides of iodine and tellurium. Their isotope ratio hadn't changed and was determined by the burn up depth of nuclear fuel at the NPP reactor which determines the amount of isotopes and their ratio in the irradiated fuel [10]. The tables 1 and 2 show the contamination reconstruction data of surface air and soil with iodine isotopes and short-lived radionuclide for Minsk and Gomel, and capacity levels of exposure dose during radioactive cloud pass [14; 15].

Table 1

Radionuclides characterizing the radiation situation in Minsk 1986 April 28–29

Radionuclide	$C_{RN\text{-}a\gamma}$, kBq/m^3	$\sigma_{RN\text{-}s\gamma}$, kBq/m^2	$P_{\gamma a}$, μR/hour (28.04.86)	$P_{\gamma a}/\sum P_{\gamma a}$, %	$P_{\gamma s}$, μR/hour (29.04.86)	$P_{\gamma s}/\sum P_{\gamma s}$, %
^{131}I	2.10	24.0	17.85	9.70	5.28	6.08
^{132}Te (^{132}I)	2.03	23.2	103	56.0	28.8	33.1
^{133}I	0.51	5.78	6.67	3.63	1.85	2.13
^{135}I (^{135m}Xe)	0.00	0.03	0.10	0.06	0.03	0.03
^{133m}Xe	0.08	–	0.07	0.04	–	–
^{133}Xe	4.27	0.00	4.57	2.48	–	–
^{95} Zr	0.33	13.3	5.41	2.94	5.44	6.27
^{95} Nb	0.34	13.7	5.82	3.16	5.91	6.80
^{97} Zr	0.02	0.7	0.32	0.17	0.32	0.37
^{99}Mo	0.83	33.4	5.12	2.78	5.00	5.76
^{103}Ru	1.34	53.9	14.7	8.00	14.0	16.1
^{106}Ru	0.42	16.7	1.83	0.99	1.67	1.92
^{134}Cs	0.12	1.8	2.38	1.29	2.41	2.77
^{136}Cs	0.04	0.8	0.94	0.51	0.92	1.06
^{137}Cs	0.25	3.70	1.16	0.63	1.18	1.36
^{140}Ba	0.29	11.8	1.15	0.62	1.29	1.49
^{140}La	0.13	5.25	6.63	3.60	6.03	6.95
^{141}Ce	0.30	12.2	0.52	0.28	0.53	0.60
^{143}Ce	0.07	2.64	0.39	0.21	0.45	0.52
^{144}Ce	0.25	10.2	0.11	0.06	0.36	0.41
^{156}Eu	0.01	0.53	0.39	0.21	0.35	0.40
^{239}Np	1.35	54.3	4.86	2.64	5.05	5.81
∑			***184***		***86.8***	

Note. $C_{RN\text{-}a}$ – radionuclide concentration in air 28.04.86; $\sigma_{RN\text{-}s}$ – surface soil contamination with radionuclides 29.04.86; $P_{\gamma a}$ – capacity of exposure dose from radioactive cloud; $P_{\gamma s}$ – capacity of exposure dose from contaminated soil.

Table 2

Radionuclides characterizing the radiation situation in Gomel 1986 April 28–29

Radionuclide	$C_{RN\text{-}a\gamma}$, kBq/m^3	$\sigma_{RN\text{-}s\gamma}$, kBq/m^2	$P_{\gamma a}$, μR/hour (28.04.86)	$P_{\gamma a}/\sum P_{\gamma a}$, %	$P_{\gamma s}$, μR/hour (29.04.86)	$P_{\gamma s}/\sum P_{\gamma s}$, %
^{131}I	42.94	482.3	364.9	9.82	106.1	6.84
^{132}Te (^{132}I)	41.49	466.0	2108	56.73	577.9	37.28
^{133}I	10.34	116.1	136.5	3.67	37.16	2.40
^{135}I (^{135m}Xe)	0.057	0.636	2.109	0.06	0.534	0.03
^{133m}Xe	1.598	–	1.466	0.04	–	–
^{133}Xe	85.31	–	91.21	2.45	–	–

Ending table 1

Radionuclide	$C_{RN\text{-}a\gamma}$, kBq/m^3	$\sigma_{RN\text{-}s\gamma}$, kBq/m^2	$P_{\gamma a}$, μR/hour (28.04.86)	$P_{\gamma a}/\sum P_{\gamma a}$, %	$P_{\gamma s}$, μR/hour (29.04.86)	$P_{\gamma s}/\sum P_{\gamma s}$, %
^{99}Mo	16.21	542.8	100.0	2.69	81.42	5.25
^{103}Ru	26.19	876.7	288.1	7.75	227.9	14.71
^{106}Ru	8.123	271.9	35.74	0.96	27.19	1.75
^{134}Cs	1.344	45.02	46.50	1.25	39.16	2.53
^{136}Cs	0.385	12.89	18.29	0.49	14.95	0.96
^{137}Cs	1.798	60.20	22.66	0.61	19.26	1.24
^{95}Zr	6.452	216	105.8	2.85	88.56	5.71
^{95}Nb	6.678	223.6	113.7	3.06	96.14	6.20
^{97}Zr	0.317	10.63	6.172	0.17	5.206	0.34
^{140}Ba	5.716	191.4	22.45	0.60	21.05	1.36
^{140}La	2.550	85.37	129.6	3.49	98.18	6.33
^{141}Ce	5.935	198.7	10.21	0.27	8.545	0.55
^{143}Ce	1.282	42.93	7.525	0.20	7.298	0.47
^{144}Ce	4.956	165.9	2.131	0.06	5.807	0.37
^{154}Eu	0.258	8.640	7.663	0.21	5.616	0.36
^{239}Np	26.37	882.9	94.93	2.56	82.11	5.30
∑			***3715***		***1550***	

Note. $C_{RN\text{-}a}$ – radionuclide concentration in air 28.04.86; $\sigma_{RN\text{-}s}$ – surface soil contamination with radionuclides 29.04.86; $P_{\gamma a}$ – capacity of exposure dose from radioactive cloud; $P_{\gamma s}$ – capacity of exposure dose from contaminated soil.

The tables 1 and 2 show that the main contribution to the capacity dose during radioactive cloud pass was made by iodine isotopes (about 70 %). The contribution of other short-lived isotopes to the capacity dose is about 30 %, the most dangerous of them are: ^{103}Ru (about 8 %), ^{95}Zr and ^{95}Nb (about 6 %), ^{140}Ba and ^{140}La (about 4 %), ^{239}Np (about 5 %) and ^{99}Mo (about 3 %) [14; 15].

Based on the above, the reconstruction of radiation situation during the active stage was carried out (from 26.04.86 to 05.05.86) [15]. The following experimental data and provisions were used to reconstruct of the radiation situation:

1. Generalized data bank for Belarus (more than 19000 points, formed in the Institute of Radiobiology of the National Academy of the Republic of Belarus [12]), containing information on the population, contamination of soil, air with iodine isotopes, ^{132}Te, ^{95}Zr, ^{95}Nb, ^{99}Mo, $^{103, 106}$Ru, ^{133}Xe, ^{140}Ba, ^{140}La, ^{239}Np, ^{156}Eu.

2. Direct measurement data of daily isotope fallout of iodine using the formula (1) and reconstruction data ^{131}I to ^{129}I [16–20]:

$$\sigma_I(t_i) = \sum_{k=1}^{i} \sigma_k \eta_k \exp(-\lambda t_i), \quad (1)$$

where σ_k — daily amount of iodine-131 fallout, kBq/m^2, given to 26.04.86; $\eta_k(t)$ – ^{131}I of the total amount of ^{131}I fallout on the day t and given to 26.04.86; t_i – the time has passed since the accident, day; λ – radioactive decay constant of ^{131}I, equal to 0.0862 1/day.

3. When there was no direct measurement data of ^{131}I, the reconstruction was carried out with ^{137}Cs data [21; 22] (minus global dropouts ^{137}Cs), according to the formula:

$$\sigma_I(t_i) = \sum_{k=1}^{i} \eta_k(t) \exp(-\lambda t_i) \kappa \sigma_{Cs}, \quad (2)$$

where t_i – the time has passed since the accident, day; $\eta_k(t)$ – ^{131}I of the total amount of ^{131}I fallout on the day t and given to 26.04.86; κ – ratio of iodine-131 fallout integral to cesium-137 fallout integral for this locality given to 26.04.86; σ_{Cs} – ^{137}Cs integral amount that fell out on the soil surface and grass at the locality, kBq/m^2 (minus global dropouts ^{137}Cs) given to 26.04.86.

Based on the data of the radiation situation reconstruction of the territory of the Republic of Belarus using GIS-technology (Quantum GIS and ArcView-10.6.1), the maps of contamination dynamics of Belarus with ^{131}I during the period from 26.04.05 to 03.05.86 were made (Fig. 3) and ^{132}Te, ^{95}Zr, ^{95}Nb, ^{99}Mo, $^{103, 106}$Ru, ^{133}Xe, ^{140}Ba, ^{140}La, ^{239}Np, ^{156}Eu (Fig. 4) [15].

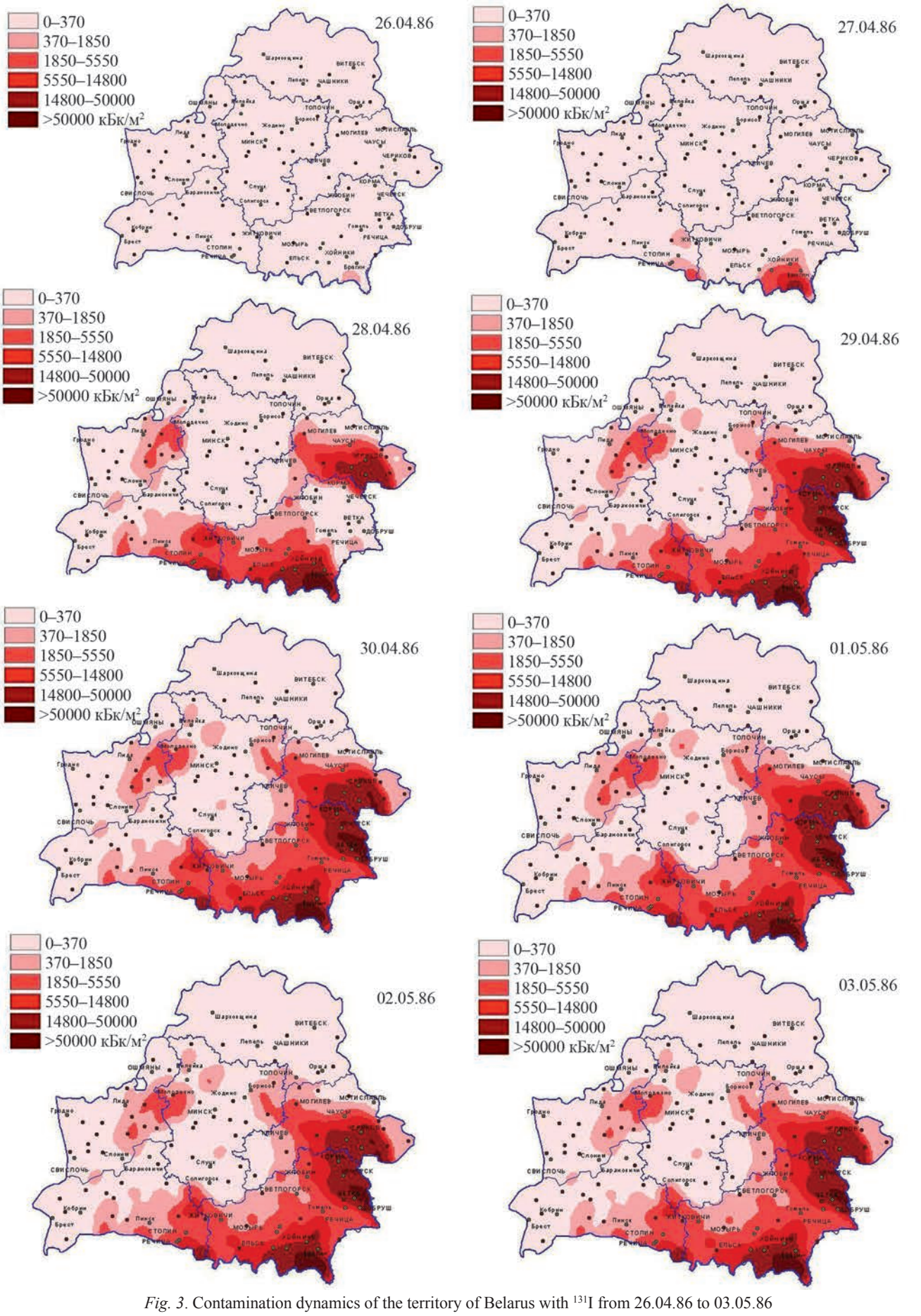

Fig. 3. Contamination dynamics of the territory of Belarus with ^{131}I from 26.04.86 to 03.05.86

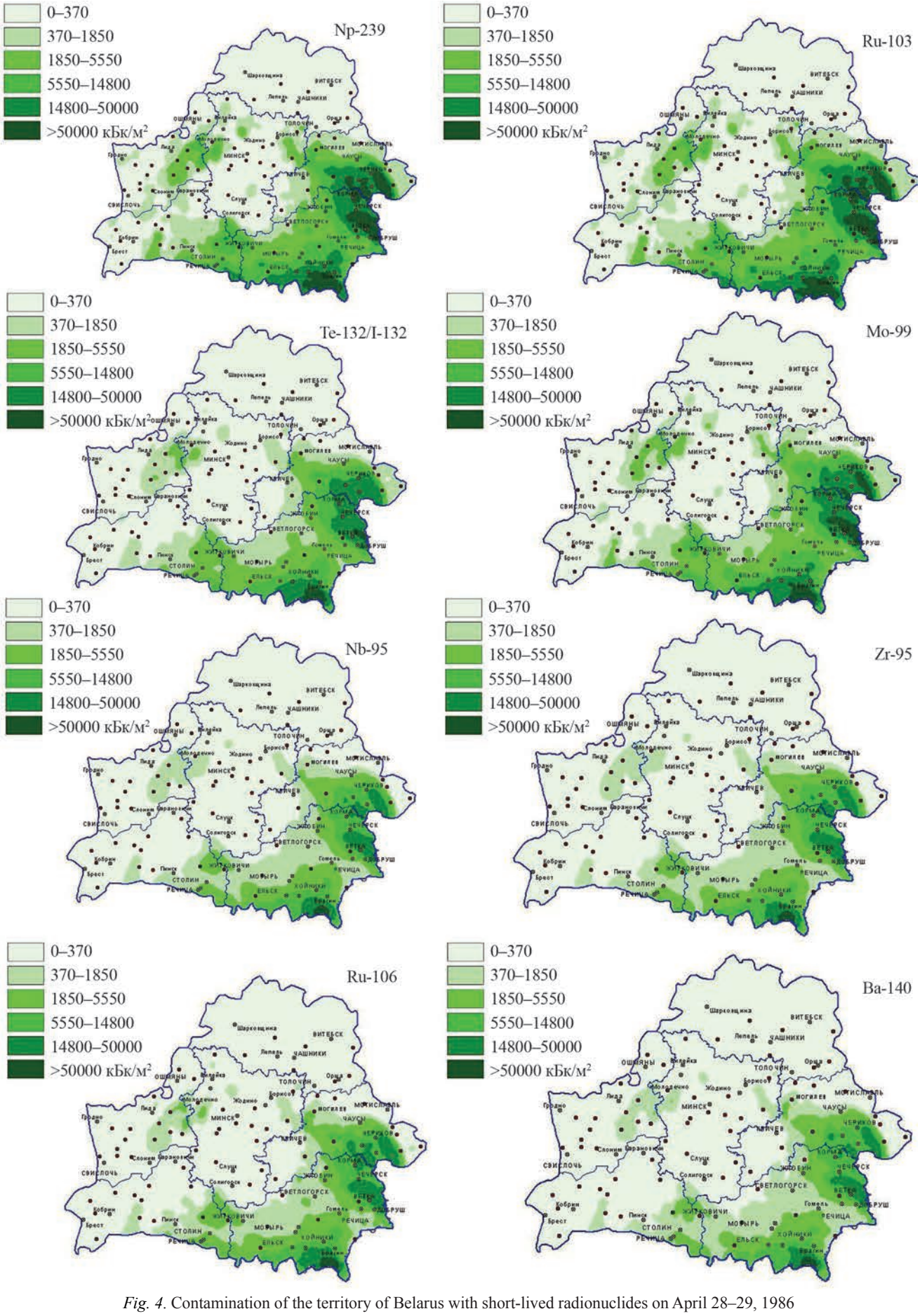

Fig. 4. Contamination of the territory of Belarus with short-lived radionuclides on April 28–29, 1986

Thus, besides iodine isotopes, a visible contribution to the formation of contamination of the territory of Belarus during accident active stage was made by the radionuclides ^{132}Te, ^{95}Zr, ^{95}Nb, ^{99}Mo, ^{103}Ru, ^{140}Ba, ^{239}Np.

Stabilization of radiation situation and III. Cesium-strontium stages. The second and the third stages are characterized by a decrease in radionuclide radiation contamination with a half-elimination period about a year by hundreds and thousands times due to natural radioactive decay. Visible destruction of fuel particles and increased migration of ^{90}Sr began [23]. Radiation situation at this stage was mainly caused by the radionuclides ^{137}Cs and ^{90}Sr (Fig. 5) [24]. ^{90}Sr migration in the soil and food chain as a result of the destruction of fuel particles is highly increased which is most common for the western trace where uranium was at primary fallout in unoxidized form. As fuel particles are destroyed, strontium enters soil solutions and migrates deep in the soil demonstrating all properties as a chemical element. It is confirmed by an increase in the fractionation coefficient of strontium to uranium with depth. There is a noticeable accumulation of ^{241}Am due to the decay of ^{241}Pu.

Based on the results of radiation monitoring of the environment, the maps of contamination of the territory of Belarus with cesium-137 were made on 10.05.1986 (Fig. 5) and contamination with strontium-90 in 2016 (Fig. 6).

Actinide stage. Due to natural decay and partly as a result of vertical and horizontal migration, contamination with ^{241}Pu, ^{137}Cs, ^{90}Sr decreased hundreds of times. Contamination is mainly determined by actinides ^{239,240}Pu and ^{241}Am while contamination with ^{241}Am is higher than contamination with $^{239,\,240}$Pu.

Chernobyl disaster led to uneven contamination of surface soil of Belarus with transuranic elements. $^{239+240}$Pu content of «Chernobyl» origin changed from $1{,}1*10^5$ Bq/m^2 for the territories located near Chernobyl NPP to average global levels in the north of the Republic of Belarus. Dangerous contamination levels are situated locally in radioactive spots of near trace. Constant growth of ^{241}Am in all ecosystem components of Belarus as a result of a natural decay of ^{241}Pu is observed (Fig. 7) [25; 26].

According to our calculations, maximum contamination level with ^{241}Am will have established by 2060 and will exceed $^{239+240}$Pu 2,7 times while the territories with contamination level with $^{238+239+240}$Pu + ^{241}Am to 1000 Bq/m^2 possibly will extend beyond 30 kilometer zone.

It should be noted that important information can be received from the analysis of radionuclide ratio concentration in the air at different periods of the accident. ^{90}Sr activity ratio to $^{239+240}$Pu for the entire observation period remained practically at the same level, on average 100 ± 10. This value coincides with ratio activity of ^{90}Sr/$^{239+240}$Pu in the fuel of exploded reactor [4; 23], while concentration ratio of ^{137}Cs/$^{239+240}$Pu in the air significantly exceeds the calculated for the fuel. It follows that on the territory of Belarus plutonium and strontium were in the form of fuel particles in the air while the main form of ^{137}Cs existence are another aerosol particles (condensation) formed as a result of cesium fall, vapored during active zone burning of nuclear reactor on «cold» aerosol particles having natural and anthropogenic origin.

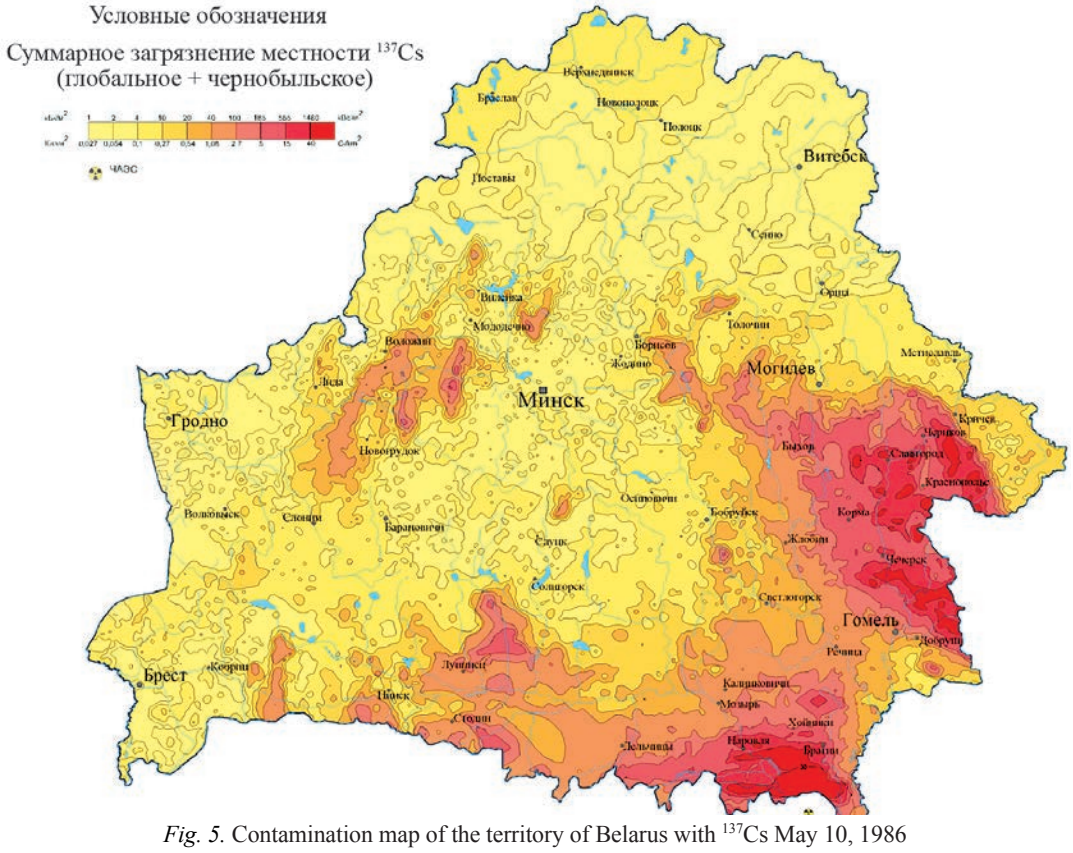

Fig. 5. Contamination map of the territory of Belarus with ^{137}Cs May 10, 1986

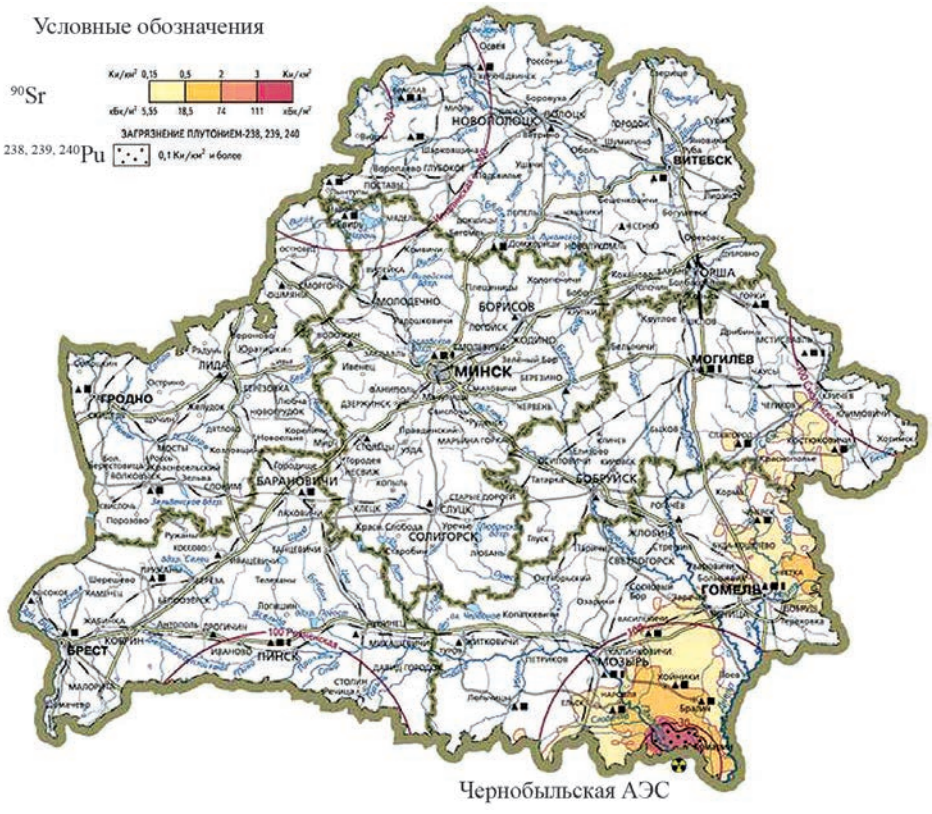

Fig. 6. Radioactive contamination of the territory of Belarus with ^{90}Sr and plutonium isotopes[1]

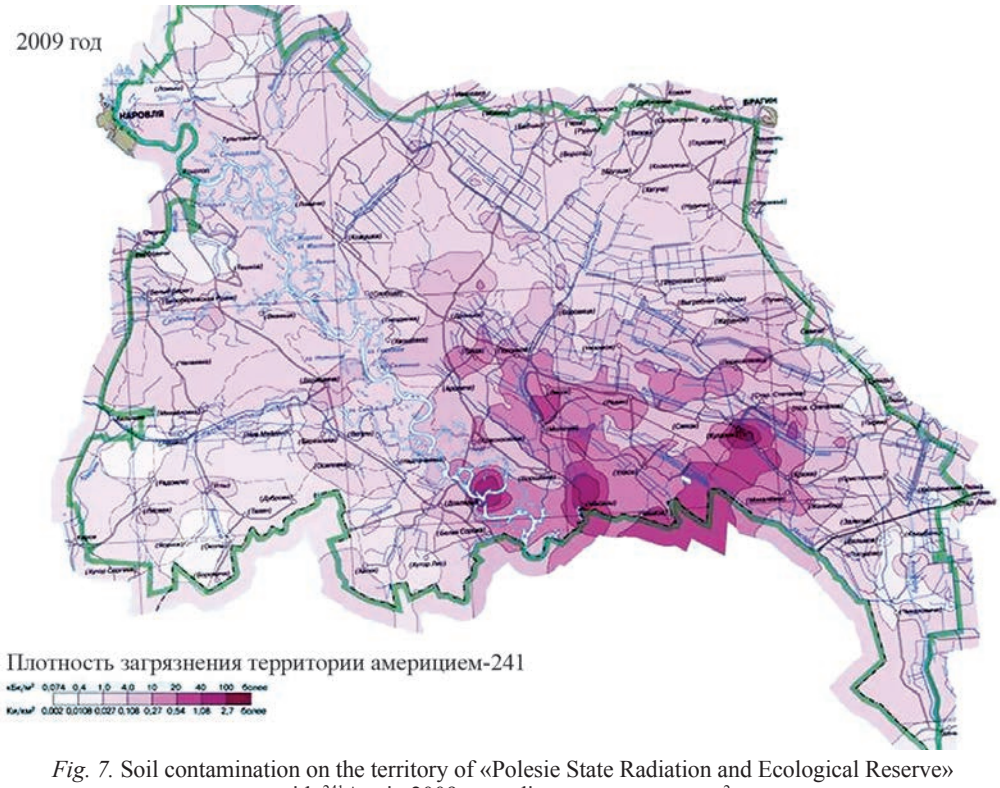

Fig. 7. Soil contamination on the territory of «Polesie State Radiation and Ecological Reserve» with ^{241}Am in 2009 according to measurements[2]

[1]Map – RB 2015 (Forecast): Radiation situation on the territory of the Republic of Belarus: Map of contamination of the territory with strontium-90 and plutonium-238, 239, 240: as of 2015 1: 3,000,000, 30 km in 1 cm / compiled and prepared for publication by the Republican Unitary Enterprise «Belkartography» in 2004. The special content was prepared by the State Institution «Republican Center for Hydrometeorology and Control».

[2]Map – RB 2015 (Forecast): Radiation situation on the territory of the Republic of Belarus: Map of contamination of the territory with strontium-90 and plutonium-238, 239, 240: as of 2015 1: 3,000,000, 30 km in 1 cm / compiled and prepared for publication by the Republican Unitary Enterprise «Belkartography» in 2004. The special content was prepared by the State Institution «Republican Center for Hydrometeorology and Control».

The analysis of radioactive contamination forecast results at the example of the defining point Masany allows making local forecast for the Masany, regional forecast for the territory of Belarus (100 km and more from the Chernobyl NPP).

The local forecast for the defining point Masany allows confirming radioactive contamination is the most long-term in Europe and includes all four stages from the iodine-neptunium phase to the actinide stage. Taking into account the peculiarities of soil contamination radionuclide composition on the territory of «Polesie State Ecological Reserve», this conclusion can be used to evaluate the radiation situation in the south-west of Gomel region, where the soil is contaminated with the radionuclides of plutonium and americium. It should be noted that the analysis of soil contamination radionuclide composition near the Chernobyl NPP on the territory of Ukraine allows making the same conclusions.

Thus, at the local level (up to 100 km from the source) the radiation situation includes all stages from the iodine-neptunium phase to the actinide stage.

The forecast at the regional level for the rest territory of Belarus allows making a conclusion that when the iodine-neptunium phase ends and the radiation situation stabilizes the soil radioactive contamination will decrease during the cesium-strontium stage. According to IAEA recommendations, this situation can be evaluated as an existing radiation situation. When the cesium-strontium stage ends (up to 100 km from the source) without the actinide stage the existing radiation situation will stop.

Conclusion

Thus at the moment of radioactive cloud passage (the first stage) the isotopes ^{131}I, ^{132}I (^{132}Te) made the main contribution to the contamination of the territory of Belarus (exposure rate dose is about 70 %). The contribution of other short-lived isotopes to exposure dose rate was about 30 %, most dose-formed of them are: ^{103}Ru (8 %), ^{95}Zr – ^{95}Nb (6 %), ^{140}Ba – ^{140}La (4 %), ^{239}Np (5 %) and ^{99}Mo (3 %). A situation of accidental radiation has developed throughout Belarus.

Radiation situation at the second and the third stages mainly caused by the radionuclides ^{137}Cs and ^{90}Sr. ^{90}Sr migration in the soil and food chain as a result of the destruction of fuel particles is highly increased which is most common for the western trace where uranium was at primary fallout in unoxidized. On the territory of Belarus, the radiation situation was characterized as an existing radiation situation.

At actinide stage, the contamination is mainly determined by $^{239, 240}$Pu and ^{241}Am while contamination with ^{241}Am is higher than contamination with $^{239, 240}$Pu. Constant growth of ^{241}Am in all ecosystem components of Belarus as a result of ^{241}Pu natural decay. On the territory of Belarus, the existing radiation situation remained at the local level (up to 100 km from the Chernobyl NPP).

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