CONSIDERATIONS ON THE REGULATION OF PRODUCTION AND CONSUMPTION WASTE MANAGEMENT DURING NUCLEAR SITE CLEANUP

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The article evaluates current legal framework regulating soil management at industrial sites with chemical contamination, in particular, soil removal and assigning it the status of production and consumption waste. It considers some features specific for the methods applied for soil categorization and waste classification, as well as waste management options as referred to their use at nuclear facilities and introduces some proposals for their adjustment.

Keywords: *decommissioning of nuclear facilities, chemical contamination of soils, categories of soil contamination, production and consumption waste, waste hazard class, radioactive waste.*

Introduction

Practical nuclear decommissioning efforts implemented under the Federal Target Program Nuclear and Radiation Safety in 2016—2035 were studied. The study shows that the measures that may pave the way for the unrestricted use of the sites [1] involve not only the removal of radioactive contaminants, but also chemicals, including heavy metal compounds, volatile organic compounds, polyaromatic hydrocarbons and other hazardous substances approved by the Order of the Government of the Russian Federation No. 1316-r of July 8, 2015 [2].

Contaminated soil management is seen as a most challenging issue associated with the chemical decontamination process. Current practice provides for soil categorization based on the inventory of contaminants contained in it and subsequent selection of an appropriate option enabling further soil use. This process may be complicated by the presence of some technical inaccuracies in the corresponding regulatory documentation, and the selection of an ultimate contaminated soil management strategy is to a large extent challenged by the lack of clear-cut solutions when the decision has to be made on its further use.

Regulations in the field of contaminated soil management were analyzed under the present study and it became clear that some of them should be amended to eliminate certain technical inaccuracies and specify the rules governing further use of contaminated soils.

The paper considers the case of nuclear facility decommissioning as a most illustrative example that may most exhaustively describe the existing algorithm followed when one needs to make decisions regarding the management of soils from industrial sites contaminated with chemicals, in particular, as it comes to soil removal and assigning them the status of production and consumption waste (PCW).

Decommissioning of nuclear facilities

Nuclear decommissioning includes, in particular, contaminated soils management implemented in keeping with the intended purpose of the site at the post-cleanup stage. In case of contaminated soil management, the decision-making flowchart involves two stages (Fig. 1) discussed in more detail in the following sections.

In practice, the nuclear decommissioning stage requires certain issues to be clarified, in particular:

- under the comprehensive engineering and radiation survey (KIRO) (Order of Rostekhnadzor No. 432 of November 11, 2019), chemical contamination may be evaluated only in certain areas where, according to technical documentation, cases of radioactive or chemical soil contamination have previously been recorded. If such data are absent, the chemical contamination assessment is not included into the preliminary inspection, and directly at the KIRO stage appropriate measures should be provided for to obtain information on the content of toxic chemicals and materials only in the systems and equipment of the studied nuclear facility. No requirements are provided in current regulations as regards the approaches to the assessment of chemical contamination. Thus, chemical contamination is monitored and assessed only in already recorded cases;
- there are no uniform requirements for permissible contamination depending on the intended soil use;
- there are no specific requirements for landfills designed for waste generated from decommissioning, which may have mixed contamination (both chemical and radioactive substances).

Evaluation of soil contamination according to its degree and level (Stage 1)

As shown in the generalized decision-making flowchart on the contaminated soil management during nuclear decommissioning (Fig. 1), in accordance with the Sanitary Rules and Norms 1.2.3685-21 Hygienic Standards and Requirements for the Safety and (or) Harmlessness of Environmental Factors for Humans [3] and Methodological Guidelines MU 2.1.7.730-99 Hygienic Assessment of Soil Quality in Populated Areas [4], the degree of chemical soil contamination is evaluated with respect to each individual substance and should take into account the actual content of the contamination components, their persistence, solubility in water, mobility in the soil and the depth of the contaminated layer.

Soil categorization is somewhat complicated by the similarity of the assessment subjects according to two concepts, i.e., *the degree of soil contamination*

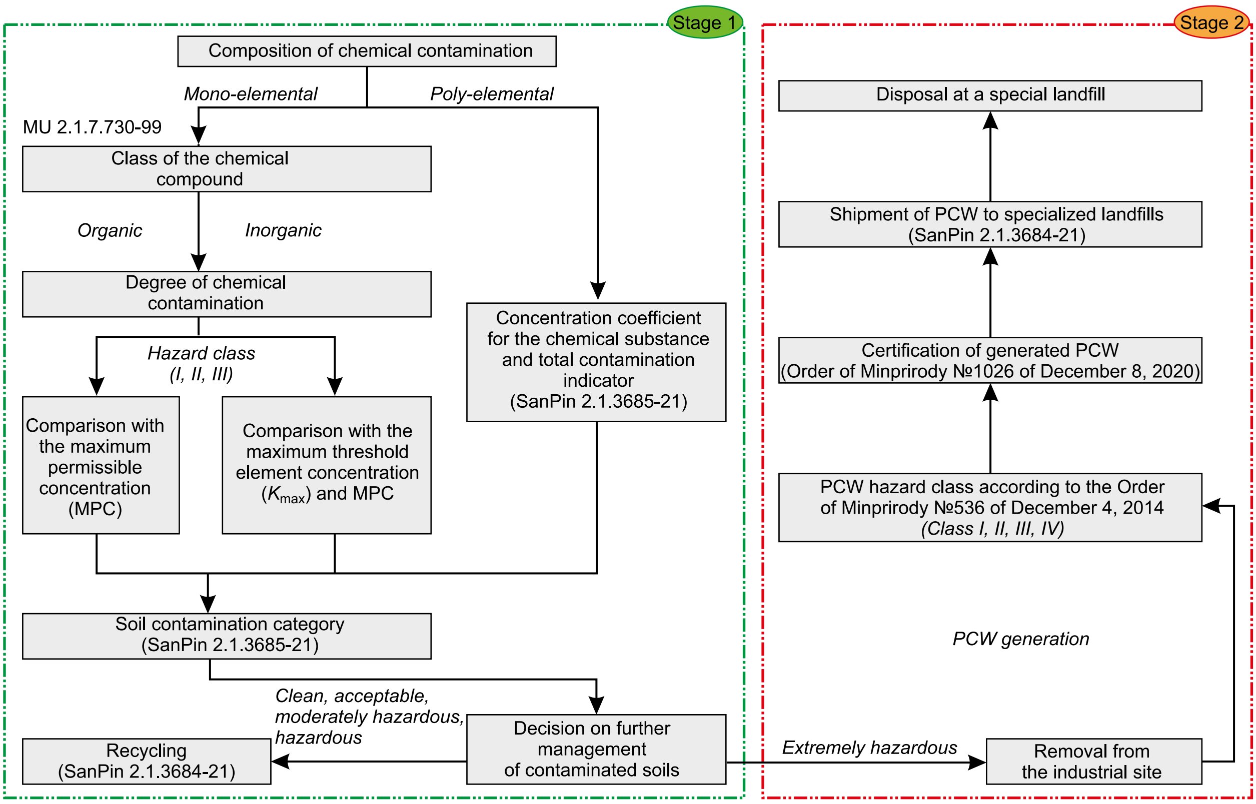

Fig. 1. Generalized decision-making flowchart for contaminated soil management followed during nuclear facility decommissioning

and *the level of chemical soil contamination,* since each of them in the current version of regulations includes separate categories that have not been harmonized with each other (Tables 1—3). It should be noted that in the sanitary rules and regulations SanPiN 1.2.3685-21, the section concerning soil contamination presents some tables discussing solely the options providing the identification of soil contamination degree and category, although the accompanying text mentions the level of chemical soil contamination.

Clause 3.2 of the letter of the Ministry of Environmental Protection and Natural Resources of the Russian Federation No. 04-25/61-5678 of December 27, 1993 On the Procedure Followed to Evaluate the Damage from Land Contamination with Chemicals indicates that the degree of land contamination is characterized by 5 levels [5]. Thus, it can be assumed that *the level of chemical soil contamination* is an integral to the concept suggesting *the degree of chemical soil contamination.*

The criteria applied to assess this indicator depend on the class of chemical substances. For example, for inorganic compounds the hazard class of a contaminant component, its maximum permissible concentration (MPC) and the maximum threshold element concentration (K_{max}) according to one of the four hazard indicators (translocation, water transport, air transport or general sanitary) (Table 1) are taken into account; for organic compounds the risks are evaluated based on their MPC and the hazard class (Table 2).

Table 1. Estimated degree of soil contamination by inorganic substances [3], [4]

Concentration in the soil (mg/kg)	Categories of soil contamination		
Hazard class of the substance	Class I	Class II	Class III
> K_{max}	Very strong	Very strong	Strong
From MPC to K_{max}	Very strong	Strong	Intermediate
From 2 background concentrations to MPC	Weak	Weak	Weak

Table 2. Estimated degree of soil contamination by organic substances [3], [4]

Concentration in the soil (mg/kg)	Categories of soil contamination		
Hazard class of the substance	Class I	Class II	Class III
> 5 MPC	Very strong	Very strong	Strong
From 2 to 5 MPC	Very strong	Strong	Intermediate
From 1 to 2 MPC	Weak	Weak	Weak

It should be emphasized that these assessment criteria are applied only in case of mono-element contamination; whereas in case of poly-element contamination one may evaluate the hazard degree based on the most toxic element having maximum concentration in the soil with no account taken of the chemical compound classes [4].

Next, the category of soil contamination is determined based on the evaluated degree of chemical soil contamination (Fig. 1) with the total contamination indicator defined as the sum of the concentration coefficients of chemical substances (Kci) seen as the main parameter. When assessing the level of chemical contamination, this indicator developed based on multiple geochemical and geohygienic studies of the environment in the cities with active contamination sources is seen as an indicator demonstrating adverse public health effects and can be calculated as follows:

$$K_{ci} = C_i / C_{\phi i} ,$$

where K_{ci} is the concentration coefficient of the *i*-th contamination component;

C_i is the actual content of the substance being measured in the soil, (mg/kg);

$C_{\phi i}$ is the regional background content of the substance being measured in the soil, (mg/kg) [3].

The chemical contamination level is established by sanitary rules as (K_{ci}) the ratio of the contaminant concentration to its background content in the soil in case of mono-element contamination; in cases of poly-element contamination, the total contamination index (Z_c) is used (Table 3):

$$Z_c = \sum (K_{ci} + \ldots + K_{cn}) - (n-1).$$

Division of Table 3 by classes of chemical substances into organic and inorganic allows us to note that for the latter, SanPiN 1.2.3685-21 sets the same contaminant concentrations for the clean and permissible soil categories (Table 3.1). If we take into account the degree of soil contamination, the clean category should be characterized by a contaminant content in the soil ranging from 1 to 2 background values, and the permissible category — from 2 background values to the MPC.

For organic substances (Table 3.2), the permissible category involves the content range from 1 to 2 MPC, which implies that the maximum permissible concentrations of harmful chemicals in the soil may exceed the limits established by the SanPiN 1.2.3685-21. Moreover, in the SanPiN 2.1.7.1287-03, the clean category refers only to high-risk objects, such as the territories of children's and educational facilities, sports, play areas, playgrounds of residential buildings, recreation areas, leisure areas,

Table 3. Evaluation of the soil contamination categories [3]

Contamination category	Total contamination index (Z_c)	Content in the soil (mg/kg)					
		Hazard class I		Hazard class II		Hazard class III	
		OC	IC	OC	IC	OC	IC
Clean	–	From background to MPC					
Permissible	<16	From 1 to 2 MPC	From background to MPC	From 1 to 2 MPC	From background to MPC	From 1 to 2 MPC	From background to MPC
Moderately hazardous	16–32	–	–	–	–	From 2 to 5 MPC	From MPC to K_{max}
Hazardous	32–128	From 2 to 5 MPC	From MPC to K_{max}	From 2 to 5 MPC	From MPC to K_{max}	> 5 MPC	> K_{max}
Extremely hazardous	> 128	> 5 MPC	> K_{max}	> 5 MPC	> K_{max}	–	–

OC – organic compounds;
IC – inorganic compounds.

Table 3.1. Evaluation of soil contamination categories for inorganic compounds

Contamination category	Total contamination index (Z_c)	Content in the soil (mg/kg)		
		Hazard class I	Hazard class II	Hazard class III
Clean	–	From background to MPC		
Permissible	< 16			
Moderately hazardous	16–32	–	–	From MPC to K_{max}
Hazardous	32–128	From MPC to K_{max}	From MPC to K_{max}	> K_{max}
Extremely hazardous	> 128	> K_{max}	> K_{max}	–

Table 3.2. Evaluation of soil contamination categories for organic compounds

Contamination category	Total contamination index (Z_c)	Content in the soil (mg/kg)		
		Hazard class I	Hazard class II	Hazard class III
Clean	–	From background to MPC		
Permissible	< 16	From 1 to 2 MPC	From 1 to 2 MPC	From 1 to 2 MPC
Moderately hazardous	16–32	–	–	From 2 to 5 MPC
Hazardous	32–128	From 2 to 5 MPC	From 2 to 5 MPC	> 5 MPC
Extremely hazardous	> 128	> 5 MPC	> 5 MPC	–

sanitary protection zones of water bodies, coastal areas, sanitary protection areas [6].

Another option that can be used to assess the degree of land contamination by chemicals based on the total contamination index (Table 4) involving the values for the clean category is discussed in the letter by the Ministry of Environmental Protection and Natural Resources of the Russian Federation of December 27, 1993 No. 04-25/61-5678 On the Procedure Followed to Evaluate the Amount of Damage from Land Contamination by Chemicals [5].

Table 4. Land contamination degree by chemicals evaluated based on the total contamination index (Z_c) [5]

Z_c	Land contamination degree	Contamination level
< 2	Permissible	1 (permissible)
2–8	Weak	2 (low)
8–32	Intermediate	3 (intermediate)
32–64	Strong	4 (high)
> 64	Very strong	5 (very high)

The data given in Table 4 link the assessments in Tables 1 and 2 with the total soil contamination index Zc, but correlate it in no way with the categorization values for soil contamination presented in the SanPiN 1.2.3685-21.

Let's consider some possible uncertainties in the choice of background values for the content of chemicals in the soil. For example, for the city of Moscow, the following indicators can be considered as such:

- concentrations in the soil samples collected from areas not being prone to any man-caused loads in accordance with the Procedure Followed to Estimate the Damage from Chemical Land Contamination approved by the Ministry of Natural Resources and Environment of the Russian Federation [5] (Table 5);
- regional background contents approved for the Russian Federation as a whole [5] (Table 6);
- recommended values (Table 7) established by the Committee for Architecture and Urban Development of Moscow (Moskomarkhitektura) [7].

Table 5. Background concentrations of elements and compounds in soil samples collected from Kolomenskoye and Borisovskie Prudy parks (mg/kg)

As	Bi	Cd	Co	Cu	Mn	Ni	Pb	Zn	Se
1	1	1	8.55	1	94	5.2	11.3	51.5	5.25
Sb	**Hg**	**Be**	**Mo**	**V**	**B**	**Cr**	**Ba**	**Sr**	**W**
1	1	0.08	1	11.6	0.76	27.25	46.25	16.05	1

Table 6. Regional background concentrations of heavy metals and arsenic in soils (mg/kg) [5]

Soils	Zn	Cd	Pb	Hg	Cu	Co	Ni	As
Sod-podzolic sandy and sandy loam	28	0.05	6	0.05	8	3	6	1.5
Sod-podzolic loamy and clayey	45	0.12	15	0.10	15	10	30	2.2
Gray forest	60	0.20	16	0.15	18	12	35	2.6
Black soils	68	0.24	20	0.20	25	15	45	5.6
Chestnut	54	0.16	16	0.15	20	12	35	5.2

Table 7. Background concentrations of chemical substances recommended by the Moscow Committee for Architecture (mg/kg) [7]

Mn	As	Cu	Zn	Cd	Cr	Pb	Ni	Hg	Co
1,260	6.6	27	52	0.3	46	26	20	0.1	7.2

Background contaminant concentrations were compared between themselves (Fig. 2) and it was shown that for some elements they may differ by 2—3 times.

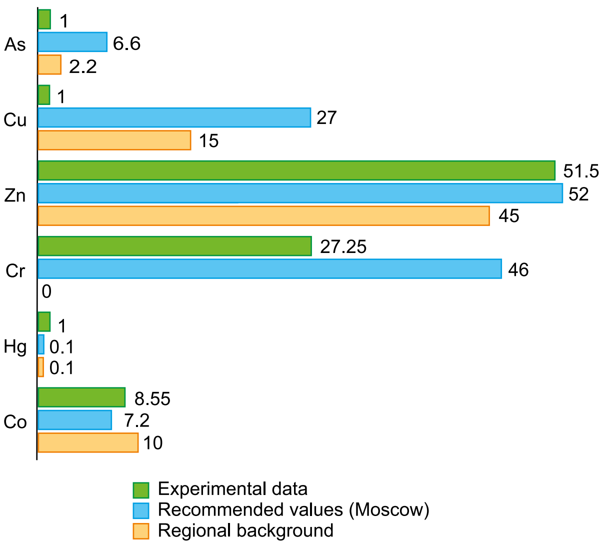

Fig. 2. Comparison of the background concentrations established for heavy metals

Based on a case study involving a contaminated soil sample referred to the extremely hazardous category collected at the pre-decommissioning stage, calculated below are the concentration coefficients of chemical substances (K_c) and the total contamination index (Z_c). According to the monograph [8], zinc, copper, lead and nickel may be present in the soils of the Karelian and East Siberian taiga. Next, based on the content of these elements in the contaminated soil sample (Table 8), it was categorized using various background concentrations (Tables 5—7).

Table 8. Contaminant concentrations in the soil sample and the corresponding background concentrations (mg/kg) [5], [7]

	Cu	Ni	Pb	Zn
Contaminant concentration in the soil sample	686.25	290.88	383.75	2542.25
$C_{ф1}$ (Borisovskie Prudy)	1	5.2	11.3	51.5
$C_{ф2}$ (RF Ministry of Natural Resources and Environment)	15	30	15	45
$C_{ф3}$ (Moscow Committee for Architecture)	27	20	26	52
K_{c1}	686.25	55.94	33.96	49.36
K_{c2}	45.75	9.70	25.58	56.49
K_{c3}	25.42	14.54	14.76	48.89

The total contamination index (Z_c) calculated based on K_{c1} and K_{c2} amounted to 822.5 and 134.5, respectively. Thus, the soil could be categorized as extremely hazardous, whereas the total index of 100.6 calculated based on K_{c3} indicated that this sample could be referred to hazardous category rather than the extremely hazardous one, which suggests a considerably different approach to such soil management.

Hazard class of production and consumption waste specified according to the degree of negative environmental impact (Stage 2).

SanPiN 2.1.7.1287-03 [6] establishes a requirement stating that soil conditions shall be monitored in the sanitary protection zones of industrial enterprises. If such study reveals chemical contamination at a level exceeding the MPC and the subsequent estimation of the chemical contamination degree results in the contaminated soil categorization as extremely hazardous (stage 1), only one option for its further use is possible, i. e., its removal and disposal at specialized landfills (Fig. 1) [9].

To be accepted by such facilities, the soil should be categorized as production and consumption waste which provides for its proper certification and identification of its hazard class according to the degree of negative environmental impact based on the methodology (Fig. 3) approved by the Order No. 536 of

$$K = K_1 + K_2 + \ldots K_m$$

↑

$$K_i = \frac{C_i}{W_i}$$

↑

$$\lg W_i = \begin{cases} 4 - \frac{4}{Z_i} & \text{for } 1 < Z_i < 2 \\ Z_i & \text{for } 2 \le Z_i \le 4 \\ 2 + \frac{4}{6 - Z_i} & \text{for } 4 < Z_i < 5 \end{cases}$$

↑

$$Z_i = \frac{4X_i}{3} - \frac{1}{3}$$

↑

$$X_i = \frac{\left(\sum_{j=1}^{n} B_j\right) + B_{inf}}{n+1}$$

K_i — hazard degree indicators for substances contained in the waste;
C_i — concentration of the *i-th* component in the waste (mg/kg);
W_i — environmental hazard degree coefficient of the *i-th* waste component (mg/kg);
Z_i — unified relative environmental hazard parameter of the waste component;
X_i — relative environmental hazard parameter of the waste component;
Z_i — unified relative environmental hazard parameter of the waste component;
B_j — the score corresponding to each evaluated primary hazard indicator of the waste component;
n — the number of evaluated primary hazard indicators of the waste component;
B_{inf} — the score corresponding to the indicator demonstrating the information support provided for the system of primary hazard indicators of the waste component.

Fig. 3. The procedure followed to calculate the hazard degree of waste for the environment

the Ministry of Natural Resources and Environment of the Russian Federation of December 4, 2014 On the Approved Criteria for Waste Assignment to I—V Hazard Classes According to the Degree of Negative Environmental Impact (hereinafter referred to as the Order) [10].

Appendix No. 4 of the Order provides standard environmental hazard degree coefficients for the i-th waste component (W_i), the unified relative environmental hazard parameter for the waste component (Z_i) and the relative environmental hazard parameter for the waste component (X_i) considering some waste components (Fig. 3). Since its approval, toxicological indicators have been extensively studied for various chemicals. It should be noted that accounting of modern data when describing the primary hazard characteristics, including the levels of lethal dose LD_{50} and lethal concentration LC_{50}^{aq}, causes a discrepancy in the ultimate K parameter values. Parameter K calculated for the contaminant composition given in Table 8 taking into account the updated toxicological indicators does not yield considerable discrepancies, whereas the updated data on LD_{50} and LC_{50}^{aq} for arsenic (Table 9) cause more noticeable discrepancies.

If one substitutes the calculated score corresponding to each evaluated primary indicator of the waste component hazard, the following values can be obtained:

$$X_i = \frac{\left(\sum_{j=1}^{n} B_j\right) + B_{inf}}{n+1} = \frac{27}{12} = 2.25;$$

$$Z_i = \frac{4X_i}{3} - \frac{1}{3} = \frac{4 \times 2.25}{3} - \frac{1}{3} = 2.67; \quad \lg W_i = Z_i.$$

Table 9. Primary component hazard indicators for arsenic

Primary hazard indicators of the waste component	Indicator value	Score	Reference
MPC_p (APC), mg/kg	10	2	[3]
Hazard class in the soil	1	1	
MPC_w (APL, ASEL), mg/l	0.01	2	
Hazard class in the water used for domestic and drinking water supply	1	1	
$MPC_{f.i.}$ (ASEL), mg/l	0.05	3	[11]
Hazard class in the water of fishery management	3		
$MPC_{a.d.}$ ($MPC_{o.t.}$, ASEL), mg/m^3	0.0003	1	[3]
Hazard class in the atmospheric air	1	1	
MPC_{fp} (MPL, MPCo), mg/kg	–	–	–
lg (S, mg/l/ $MPC_{w\ в}$, mg.l)	< 1	4	[12]
lg (C_{sat}, mg/m^3/ $MPC_{w.a.}$)	–	–	–

End of Table 9

Primary hazard indicators of the waste component	Indicator value	Score	Reference
lg (C_{sat}, mg/m^3/ MPC$_{a.d.}$ or MPC$_{o.t.}$)	–	–	–
lg K_{ow} (octanol/water)	–	–	–
LD_{50}, mg/kg	145	2	[13]
LC_{50}, mg/m^3	–	–	–
LC_{50}^{aq}, mg/l/96 h	28.68	3	[12]
BD = BOD$_5$ / COD 100 %	–	–	–
Persistence (transformation in the natural environment)	–	–	–
Bioaccumulation (behavior in the food chain)	–	–	–
Information support (B_{inf})	n > 0.9	4	

MPC$_p$ — maximum permissible concentration of a substance in the soil
APC — approximate permissible concentration
MPC$_w$ — maximum permissible concentration of a substance in the water of water bodies used for drinking and domestic water supply
APL — approximate permissible level
ASEL — approximate safe exposure level
MPC$_{f.i.}$ — maximum permissible concentration of a substance in the water of water bodies of fishery importance
MPC$_{a.d.}$ — average daily maximum permissible concentration of a substance in the atmospheric air of populated areas
MPC$_{o.t.}$ — maximum one-time permissible concentration of a substance in the atmospheric air of populated areas
MPC$_{fp}$ — maximum permissible concentration of a substance in food products
MPL — maximum permissible level
MPCo - maximum permissible content
S — solubility of waste component (substance) in water at 20 °C
C_{sat} — saturating concentration of a substance in air at 20 °C and normal pressure
MPC$_{w.a.}$ — maximum permissible concentration of a substance in the atmospheric air of a working area
K_{ow} — partition coefficient in the octanol/water system at 20 °C
LD_{50} — average lethal dose of the component in milligrams of the active substance per 1 kg of live weight causing death of 50 % of the experimental animals with a single oral administration under standardized conditions
LC_{50} — average lethal concentration of the substance causing death of 50 % of the experimental animals with inhalation intake under standardized conditions
LC_{50}^{aq} — average lethal concentration of the substance in water causing death of 50 % of all hydrobionts accounted for in the experiment (for example, fish) after 96 hours
BD — biological dissimilation
BOD$_5$ — biological oxygen demand expressed in milliliters of O_2/l per 5 days
COD — chemical oxygen demand expressed in milliliters of O_2/100 l

If one compares the values obtained using updated toxicological data with those specified in the Order (Table 10), a discrepancy in the parameter values is observed, which in further calculations, especially in case of multi-component waste, would cause uncertainties when selecting the hazard class of waste.

Table 10. Parameters compared to determine the hazard degree of arsenic

	Parameter		
	X_i	Z_i	W_i
Order	2.27	2.69	493.55
Calculation	2.25	2.67	467.74

For a clear illustration, let's consider the case of waste with an arsenic concentration of 4,900 mg/kg, typical of coal ash deposits or mining waste [14]. The waste hazard degree for the environment (K) and the corresponding class (Table 11) can be evaluated as follows:

$$K_{order} = 4{,}900/493.55 = 9.93,$$

$$K_{calc} = 4{,}900/467.55 = 10.48.$$

Table 11. Environmental hazard degrees for production and consumption waste (K) by hazard classes

Hazard class of the waste	Environmental hazard degree of the waste (K)
I	$10^6 \geq K > 10^4$
II	$10^4 \geq K > 10^3$
III	$10^3 \geq K > 10^2$
IV	$10^2 \geq K > 10$
V	$K \leq 10$

As a practical example, Table 12 shows a component-by-component calculation of a contaminated soil sample collected from an industrial site in Moscow, which, in terms of its chemical soil contamination level was referred to the extremely hazardous category since the maximum permissible concentration of heavy metals was exceeded.

Table 12. Component-by-component calculation of a contaminated soil sample

Component	C_i (mg/kg)	X_i	Z_i	lg W_i	W_i (mg/kg)	K_i
Arsenic	54.38	2.27	2.69	2.69	493.55	0.110
Cadmium	6.75	2.12	2.49	2.49	309.03	0.0218
Copper	686.25	2.84	3.45	3.45	2 840.10	0.242
Manganese	1 287.50	3.15	3.87	3.87	7 356.42	0.175
Nickel	290.88	2.64	3.19	3.19	1 536.97	0.189
Lead	383.75	2.306	2.81	2.81	650.63	0.590
Zinc	2542.25	2.8	3.4	3.4	2 511.89	1.012
Mercury	< 0.1	1.79	2.05	2.05	113.07	0.000884
Chromium	243.75	2.92	3.56	3.56	3 630.78	0.0671
Strontium	56.90	3.09	3.79	3.79	6 118.81	0.00093
Benzene	2.41	2.14	2.52	2.52	331.13	0.00728
Toluene	0.95	2.69	3.25	3.25	1 778.28	0.000534
Benz(a)pyrene	0.025914	1.6	1.8	1.778	59.97	0.000432
Soil	994 444.10	4*			10^{6}*	0.994
					Total:	3.411

* Naturally occurring components are virtually harmless waste with a relative environmental hazard parameter (X) of 4 and, consequently, an environmental hazard coefficient (W) of 106 [9].

The results obtained show that, given the same concentration of a harmful chemical substance, waste can be referred to different hazard classes depending on the approach used to determine the parameters Wi, Zi and Xi.

Conclusion

Regulatory framework was evaluated and some key uncertainties in assessing the category of soil contamination were identified, namely, those associated with the calculated total contamination index, as well as the variability of background contaminant concentrations. When production and consumption waste is referred to a particular hazard class, the calculated parameters may change depending on the availability of data required to assess the primary hazard indicators for the waste components, which complicates further categorization. In case if the contaminated soils are categorized incorrectly, the rules regulating their further use are not observed, whereas inaccuracy in referring production and consumption waste to a specific category according to the hazard class may result in the disposal of hazardous contaminants at household landfills not designed for this purpose and having inadequate engineered barriers. To eliminate such situations, recommendations have been provided to improve the key provisions of regulatory legal acts discussing contaminated soil categorization and the possibility of their further use:

- the data on primary hazard indicators for waste components presented in the Order of the Ministry of Natural Resources and Environment No. 536 of December 4, 2014 shall be updated based on modern laboratory studies and the list of substances for which hazard coefficients have been determined in accordance with the list approved by the Order of the Government of the Russian Federation of July 8, 2015 No. 1316-r;
- uniform requirements that should be complied with when determining the soil contamination degrees, soil categories and subsequent management procedures if they are categorized as production and consumption waste shall be specified and possible discrepancies shown in this article shall be eliminated;
- regulatory provisions regulating nuclear decommissioning shall be supplemented to provide for mandatory assessment of building structures, equipment and site soils in terms of their chemical contamination, followed by appropriate categorization of the generated waste and proper decision-making on the waste management methods.

References

1. *Problemy yadernogo naslediya i puti ikh resheniya. Vyvod iz ekspluatatsii* [Nuclear legacy challenges and

ways to address them. Decommissioning]. Vol. 3. Under the general editorship of L. A. Bolshov, N. P. Laverov, I. I. Linge. Moscow, 2015. 316 p.

2. Order of the Government of the Russian Federation of July 8, 2015 No. 1316-r (as amended on May 10, 2019) *"Ob utverzhdenii perechnya zagryaznyayushchikh veshchestv, v otnoshenii kotorykh primenyayutsya mery gosudarstvennogo regulirovaniya v oblasti okhrany okruzhayushchey sredy"* [On the Approved List of Contaminants Subject to State Regulation in the Field of Environmental Protection].

3. 1.2.3685-21. *Gigiyenicheskiye normativy i trebovaniya k obespecheniyu bezopasnosti i (ili) bezvrednosti dlya cheloveka faktorov sredy obitaniya* [Hygienic Standards and Requirements for the Safety and (or) Harmlessness of Environmental Factors for Human].

4. *Gigiyenicheskaya otsenka kachestva pochvy naselonnykh mest: Metodicheskiye ukazaniya* [Hygienic assessment of soil quality at contaminated sites: Guidelines]. Moscow, Federal Center for State Sanitary and Epidemiological Surveillance of the Ministry of Health of Russia Publ., 1999. 38 p.

5. Letter from the Ministry of Environment Protection and Natural Resources of the Russian Federation December 27, 1993 No. 04-25/61-5678 *"O poryadke opredeleniya razmerov ushcherba ot zagryazneniya zemel' khimicheskimi veshchestvami"* [On the Procedure Implemented to Evaluate the Damage from Land Contamination by Chemicals].

6. *Sanitarno-epidemiologicheskiye trebovaniya k kachestvu pochvy: Sanitarno-epidemiologicheskiye pravila i normativy* [Sanitary and epidemiological requirements for soil quality: Sanitary and epidemiological rules and standards]. Moscow, Federal Center for State Sanitary and Epidemiological Surveillance of the Russian Ministry of Health Publ., 2004. 16 p.

7. Directive of the Committee on Architecture and Urban Planning of Moscow of March 11, 2004 No. 5 *"Ob utverzhdenii Instruktsii po inzhenerno-geologicheskim i geoekologicheskim izyskaniyam v g. Moskve"* [On the Approved Instructions for Engineering-Geological and Geoecological Surveys in Moscow].

8. Dobrovolsky V. V. *Geografiya mikroelementov. Global'noye rasseyaniye monografiya* [Geography of microelements. Global dispersion]. Moscow, Mysl Publ., 1983. 272 p.

9. SanPiN 2.1.3684-21. *Sanitarno-epidemiologicheskiye trebovaniya k soderzhaniyu territoriy gorodskikh i sel'skikh poseleniy, k vodnym ob"yektam, pit'yevoy vode i pit'yevomu vodosnabzheniyu naseleniya, atmosfernomu vozdukhu, pochvam, zhilym pomeshcheniyam, ekspluatatsii proizvodstvennykh, obshchestvennykh pomeshcheniy, organizatsii i provedeniyu sanitarno-protivoepidemicheskikh (profilakticheskikh) meropriyatiy* [Sanitary and epidemiological requirements for the maintenance of territories in urban and rural settlements, water bodies, drinking water and drinking water supply to the population, atmospheric air, soils, residential premises, operation of industrial and public premises, organization and implementation of sanitary and anti-epidemic (preventive) measures].

10. Order of the Ministry of Natural Resources and Ecology of the Russian Federation *"Ob utverzhdenii Kriteriyev otneseniya otkhodov k I-V klassam opasnosti po stepeni negativnogo vozdeystviya na okruzhayushchuyu sredu"* [On Approved Criteria for Waste Assignment to Hazard Classes I-V According to the Degree of Negative Impact to the Environment] of December 4, 2014 No. 536.

11. Order of the Ministry of Agriculture of the Russian Federation No. 552 of December 13, 2016 *"Ob utverzhdenii normativov kachestva vody vodnykh ob"yektov rybokhozyaystvennogo znacheniya, v tom chisle normativov predel'no dopustimykh kontsentratsiy vrednykh veshchestv v vodakh vodnykh ob"yektov rybokhozyaystvennogo znacheniya"* [On Approved Water Quality Standards for Water Bodies of Fishery Importance, Including Standards for the Threshold Concentrations of Harmful Substances in the Waters of Water Bodies of Fishery Importance].

12. *Vrednyye veshchestva v promyshlennosti. Spravochnik dlya khimikov, inzhenerov i vrachey. Tom III. Neorganicheskiye i elementorganicheskiye soyedineniya* [Harmful substances in industry. Handbook for chemists, engineers and doctors. Volume III. Inorganic and organoelement compounds]. Ed. N. V. Lazarev and I. D. Gadaskina. Leningrad, Khimiya Publ., 1977. 608 p.

13. *Pasport bezopasnosti khimicheskoy produktsii. Mysh'yak* [Safety data sheet for chemical products. Arsenic]. Official website of Merck. — URL: https://www.sigmaaldrich.com/RU/ru/sds/aldrich/267961 (accessed on: 02.04.2024).

14. Putilina V. S. *Povedeniye mysh'yaka v pochvakh, gornykh porodakh i podzemnykh vodakh. Transformatsiya, adsorbtsiya / desorbtsiya, migratsiya* [Behavior of arsenic in soils, rocks and groundwater. Transformation, adsorption / desorption, transfer] V. S. Putilina, I. V Galitskaya, N.I. Uganova // Ecology. Series of analytical reviews of world literature, 2011. No. 97. 249 p.

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