Indicators and Factors Resulting in Crisis Phenomena Related to the Environment Hazard of Accumulated Mineral Processing Wastes at Closed Mining Enterprises

L T Krupskaya¹², D A Golubev¹², K A Kolobanov¹²

¹Department of Forest Protection and Forest Ecology, Far East Scientific Research Institute of Forestry, 71 Volochaevskaya street, Khabarovsk 680030, Russian Federation
‡Department of Ecology, Resource Use and Life Safety, Pacific National University, 136 Tichookeanskaya Street, Khabarovsk 680035, Russian Federation

E-mail: ecologiya2010@yandex.ru

Abstract. The article presents the results of multi-year research within the limits of closed mining enterprises impact in the Far Eastern Federal District (FEFD). In the last century, here, a large amount of sulphidized toxic mineral processing wastes, stored in tailing dumps, negatively affecting the environment, was accumulated. Unfortunately, their conservation and reclamation have not been carried out; they pose a huge threat not only to the ecosphere, but also to public health. Therefore, the aim of the study was to identify the indicators and factors causing crisis phenomena related to environment hazard of accumulated toxic waste and to substantiate the possibility of reducing their negative impact on biosphere components and human health.

Natural and mining technogenic systems formed in the last century by the activity of closed mining enterprises in the Amur River basin, having biosphere importance, were the object of the study.

The following methods were used: systematization, scientific forecasting, physical and chemical, biological methods, as well as mathematical modeling, GIS-technologies, etc.

The article substantiates the necessity of effective solution of the above problem. The present state of tailing dumps has been studied and it has been established that the waste is of the second class (high-hazard). It is revealed that the level of technogenic pollution of environment objects exceeds regional background indicators in dozens (up to 28-46) times, and MPC - in hundreds, up to 225 and more, times. It was shown that the surface of the tailing dumps has not overgrown naturally for 30 years. The results of the patent search and our own experimental research allowed us to develop technological solutions to ensure environment safety of mineral processing toxic wastes. The principles of ensuring environment safety of tailing dumps containing toxic wastes have been developed. New methods of their surface productivity replenishment using innovative approaches have been created, their novelty was confirmed by the Patents of the Russian Federation.

1. Introduction

In the last century, social and economic processes in the tin mining industry in Russia [1] could not but affect the environmental safety of mining in the Far Eastern Federal District (FEED). There are a number of negative trends in this area [2]. Accumulated damage in the form of tailing dumps, containing a large
number of toxic contaminants, as a result of past activities of closed tin mining enterprises, requires an urgent organization of work to assess and gradually eliminate its environmental impact [3]. The verdict of this task is one of the conditions for achieving the aim of the Concept for Long-Term Socio-Economic Development of the Russian Federation until 2020 to improve the quality of the environment and environmental conditions of human life [4].

The analysis and generalization of domestic and foreign experience in solving these problems indicates that the problem of elimination of the accumulated damage consequences in the last century has been on the agenda for more than twenty years. It is connected with mass scale and, frequently, uncontrolled closing of the mining enterprises and other dangerous objects, both in Russia, and abroad. For example, the article by K.A. Gegiev with co-authors (2018) [5] considers the current state of the Tyrnyauz tailing dump of the closed Tyrnyauz tungsten-molybdenum combine (TTMC, Kabardino-Balkaria), which is currently causing great concern. Erosion and landslide processes are actively developing here, with sill flow formation along the Gizhgit river bed.

Ivanova O.A. et al (2016) [6] analyzed the state of the most environmentally neglected part of Baikal natural territory, namely: Zakamensky district of the Republic of Buryatia, where tungsten ores were developed and large volumes of wastes from their processing were accumulated in the last century. The ecological situation here is difficult and even critical. All natural components are polluted. Oxidation of sulfide minerals of the ore field with the formation of sulfuric acid and the removal of hazardous chemical elements from the dumps with mine, pit and infiltration waters led to contamination of a number of water streams in the basin of the Dzhida River, which are the most polluted in the Lake Baikal basin. The authors believe that the lack of documentation in the Russian Federation that would strictly require the responsibility for the past environmental damage is a significant gap.

The article by Pashkevich M.A. et al. (2012) [7] presents the results of the study to assess the landscape and geochemical situation in the area of the tailings of the apatite-nepheline concentrating plant (ANOF-2, Apatity). Violations within the limits of impact of the studied production facility are revealed. It was concluded that under the conditions of severe environmental situation prevailing in the area under study and the need to reduce the technogenic load, the issue of the possibility of developing a balanced strategy of environmental safety management of the ANOF-2 tailings becomes particularly important.

At the territory of Tyrnyauz tungsten molybdenum combine (TTMC, Kabardino-Balkaria) and Sadon lead-zinc combine (Republic of North Ossetia-Alania), Gurbanov A.G. with co-authors (2015, 2016) [8, 9] carried out a complex of geochemical research, which includes a comprehensive analysis of various surface waters, soils of agricultural lands and natural pastures, buried industrial wastes of TTMC, and open-pit dumps using modern analytical and instrumental methods. As a result of the synthesis of the data obtained, taking into account the geological, geochemical and physical-geographical peculiarities of this area, the main sources of natural environment pollution, represented by two groups - technogenic and natural, were recognized.

The researchers have proved that to reduce the risk of human losses, minimize the possible material damage from natural and technogenic disasters, reduce the negative impact on the environment in the region and on public health, it is necessary to utilize completely the industrial waste accumulated in the TTMC tailing dumps, with obligatory preliminary extraction of economically valuable metals and toxicant elements from them. As a priority measure to reduce the negative impact on the environment in the area of TTMC operations and adjacent areas, the creation of the integrated technology for processing technological waste with its gradual disposal, as well as the construction of stream water intakes, primarily in the Mukulansky openpit mine, with a series of treatment filters in the form of ion-exchange columns of various types, is proposed.

In Gurbanov's A.G. et al (2016) [9] opinion, the priority task for the Sadon lead-zinc combine (SLZC) is the temporary isolation of waters, first of all, discharged through the pipe from the tailing dump into the Ardon River, as well as the Arkhondon River, which are the main suppliers of toxicant elements to the Ardon River (with extraction of a complex of elements with concentration above MPC for drinking water). This measure will significantly reduce the inflow of these elements into the main waterway and
improve the environmental situation in the area of SLZC operation and adjacent areas. Besides, in the process of extraction of the elements complex it is quite virtually to obtain by-product pure oxides of a number of precious metals (Pb, Zn, Cd, Sb, Bi, etc.), which will significantly increase the economic attractiveness of this measure.

D.N. Chigoyeva et al. (2018) [10] studied the Ardon River status below the discharge from the tailing dump of the Sadon lead-zinc combine (SLZC). It was found out that the long history of lead-zinc deposits development in Sadon mining area has led to the formation of extensive halos of surface watercourses chemical pollution, corresponding to the category "ecological disaster". Their monitoring necessity within the limits of the tailing dump impact was substantiated.

Kachor O.L. et al. (2019) [11] revealed the scale of contamination of three mining industrial zones in the Irkutsk Region and Trans-Baikal Territory on the basis of geo-ecological and geochemical monitoring. Feasibility of sludge-lignin ashes (wastes of Baikal Pulp and Paper Mill) using for neutralization of toxic soil mixtures was shown. Possibility of sorption of residual (after reagent treatment) contents of arsenic mobile forms using modified coal sorbents for the most complete extraction of dangerous toxicant until contaminants MPC was revealed. The obtained results are of great practical importance for realization of the chemical immobilization method of As mobile ion forms in the technogenesis zone. The same conclusions were made by foreign scientists [12-14].

Article by Antonio R. et al. (2015) [15] is devoted to the assessment of the particles dispersion risk and contamination with trace elements from the waste dumps of the Riotinto mine (in southwest Spain). In this study, a model has been developed to delineate the risk zones affected by atmospheric dispersion of particles from mine waste dumps in order to assess their impact on soil and population due to the concentration of toxic chemical element compounds in them [16].

Zhigang H. and co-authors (2018) [17] studied the distribution of heavy metal compounds and made an assessment of soil contamination within the boundaries of the impact of the lead-zinc mine, located in Inner Mongolia (China). In this case, the Nemerov index and the index of potential environmental risk were used, which allowed to identify a high level of their technogenic pollution.

Researches by Sung-Min Kim and others (2016) [18] have proven that the highest risk is posed by the abandoned mines in Korea. The studies by Rosario García-Giménez et al (2017) and Gbadebo A.M. et al. (2014) [19, 20] have shown that mine tailings have an intense impact on soil contamination within the boundaries of the abandoned Monica mine (Bustarviejo) in the Autonomous region of Madrid and in south-western Nigeria.

The studies by Mayra Peña-Ortega with co-authors (2019) [21] of the environment assessment and soil erosion calculation at abandoned mine tailing dumps in the semi-arid zone of northwestern Mexico are of great interest. The problem was studied using unmanned aerial vehicles (UAVs) combined with geochemical data to assess erosion processes and taking into account the contamination and danger indicators of tailings dumps containing toxic heavy metal compounds and arsenic.

**Aims and tasks.** The aim of the studies was to identify the indicators and factors contributing to the crisis related to the environment hazard of accumulated toxic waste and to justify the possibility of reducing its negative impact on biosphere components and human health. Based on the research aim, the following tasks were identified: 1. To analyze and generalize the existing experience of studying the above problem in Russia and abroad; 2. To reveal the main sources of creation of crisis situations, criteria and factors of their occurrence hazard in connection with the accumulated toxic wastes of mineral processing at the closed mining enterprises; 3. To assess the ecological hazard of the accumulated mineral processing wastes; 4. To develop the principles and measures for the ecological safety of the tailing dumps with toxic wastes and eco-systems normal functioning within their impact.

2. **Object and methods of research**

Expeditionary field studies within the limits of the closed mining enterprise wastes impact were carried out in 2010-2018. The natural and mining technogenic systems formed in the last century by the activity of currently closed mining enterprises located in the Amur River basin of the biosphere value were the object of the study. They include Solnechny GOK (Mining and Processing Combine) (in the
Khabarovsky Krai), Khingansky GOK (Mining and Processing Combine) (in the Jewish Autonomous Region), Khristalnensky Mining and Processing Combine (in the Primorsky Krai). Its components are: atmospheric air, water, soil, as well as plant and animal organisms, microorganisms and human, as well as mining waste, machinery and technology. Generally accepted physical-chemical, chemical, biological and mathematical-statistical methods are used in research.

Estimation of potential risks of soil contamination with heavy metal compounds from the tailings dump on the single factor pollution index (PI) and pollution load index (PLI) was made using equations (1) and (2) (according to the methods set out in the article by Mari Luz García-Lorenzo et al., 2019 [22]):

\[
PI = \frac{C_{\text{soil}}}{C_{\text{background}}}
\]

\[
PLI = (PI_{\text{Co}} + PI_{\text{Cu}} + PI_{\text{Zn}} + PI_{\text{As}} + PI_{\text{Mo}} + PI_{\text{Sn}} + PI_{\text{Hg}} + PI_{\text{Pb}})^{1/8}
\]

where PI is the only factor, the pollution index of each metal and Csoil and Cbackground are the metal concentrations in the soil and background sample, respectively, (mg/kg). PI < 1 (not contaminated); 1 ≤ PI < 2 (slightly contaminated); 2 ≤ PI < 3 (moderately contaminated); PI ≥ 3 (heavily contaminated).

PLI is the pollution load index, and n is the number of estimated pollutants (five in our study). PI is a single pollution factor for each metal: PLI < 2 (moderate - non-contaminated); 2 ≤ PLI < 4 (moderately polluted); 4 ≤ PLI < 6 (heavily polluted); PLI > 6 (very heavily polluted).

In addition, PI and PLI indicators have also been calculated to assess the mobilization of potentially toxic elements (PTE) in water. The natural mobility of PTE was studied by water extraction, which is a soluble fraction. The natural mobility indices for chromium (NMInCr), nickel (NMInNi), copper (NMInCu), zinc (NMInZn), strontium (NMInSr), tin (NMInSn), mercury (NMInHg) and lead (NMInPb) compounds have been calculated as a ratio between PTE concentrations and its background values (3):

\[
NMIn_n = \frac{C_{\text{sample after water extraction}}}{C_{\text{background after water extraction}}}
\]

The Natural Mobility Index (NMI) is defined as the n-th root of a product of n indicators of natural mobility. In our case (4):

\[
NMI = (NMIn_{\text{Cr}} \times NMIn_{\text{Ni}} \times NMIn_{\text{Cu}} \times NMIn_{\text{Zn}} \times NMIn_{\text{Sr}} \times NMIn_{\text{Sn}} \times NMIn_{\text{Hg}} \times NMIn_{\text{Pb}})^{1/8}
\]

The results of the study are presented in the table where the indicator values below 2 mean low mobility; values between 2 and 4 mean moderate mobility; values between 4 and 6 mean significant mobility; and values above 6 indicate very high mobility.

The geo-accumulation index in soils (by to Jiang F. et al., 2019 [23]), proposed by Muller (1969) [24], was calculated by formula (5):

\[
I_{\text{geo}} = \log_2 \frac{C_n}{1.5 \times BE_n}
\]

where: Cn is the measured concentration of heavy metal compounds in a sample; BEn is the geochemical background mean value of the measured elements. The results of calculation of the geo-accumulation index (Igeo) will be shown in the table with the levels selection: from less than 0 to more than 5, indicating the degree of contamination from virtually uncontaminated to heavily contaminated.

The results were processed in MS Excel, the figures were processed using Photoshop, MS Office Picture Manager, Paint, MS Visio.

3. Results and discussion

Risk analysis in the area under study is important as a process of identifying individual sources of hazard and predicting their possible negative impact on the ecosystems in order to orient the Far Eastern Federal District towards sustainable development.
The results of our research allowed us to identify the following main factors that cause crisis phenomena and lead to environmental risks of storage of accumulated mineral processing wastes in the conditions of closed mining enterprises Solnechny GOK and Kristalnensky GOK: 1) presence of toxic wastes as sources of intensive negative impact on the ecosphere; 2) environmental stress of the territory and peculiarities of orographic and bioclimatic conditions, as well as ecological capacity; 3) a degree of the territory development; 4) a number of population within the limits of tailing dumps impact; 5) imperfection of environmental legislation and absence of mining and ecological monitoring of environment objects changes within the limits of toxic wastes impact.

The study of factors made it possible to propose the following classification of environmental crisis situations: 1) Technogenic-ecological, related to accumulated environment damage; 2) Technogenic impact contributing to intensive ecosphere pollution; 3) Social-ecological, related to living of population at technogenic polluted territory.

The impact of the above negative factors may lead to further aggravation of the environmental situation in the studied Solnechny (Khabarovsky Krai) and Kavalerovsky tin ore districts (Primorsky Krai) in the FEFD in the near future if no urgent and effective measures are taken to overcome them in the near years. Any of these risks may result in the following primary environmental and economic problems:

1. Decrease of the quality of human and biota habitats;
2. Lack of responsibility for: 1) habitat quality; 2) protection of health of population living in a mining settlement; 3) compliance with safety measures (e.g. compensation claims);
3. Costs of eliminating technogenic pollution and its consequences;
4. Non-compliance of applied technological solutions with environmental standards in the last century;
5. Incorrect solution of environmental problems and public discontent;
6. Inconsistency with international standards.

Below environmental risks at the closed mining enterprises of the FEFD are considered:

3.1. Technogenic and environmental risks associated with accumulated environmental damage

Among the environmental reasons the following are singled out: firstly, the location of objects that are ecologically incompatible with the natural complex, and secondly, the faulty assessment or underestimation of the environmental consequences of the natural landscapes transformation in the process of mineral development in the last century.

Intensive development of mineral resources in the Far Eastern Federal District of Russia has resulted in accumulation of a large number of toxic sulphidized mineral processing wastes, which have a powerful negative impact on the environment and human health. In the last century they were stored in tailing dumps, which have not been currently unchecked and are considered by us as ecological damage. They include: Solnechny GOK (Solnechny District, Khabarovsky Krai), Khrustalnensky GOK (Kavalerovsky District, Primorsky Krai), Khingansky GOK (Obluchensky District, Jewish Autonomous Region), Karamkensky GOK (Khasynsky District, Magadan Region) and others.

Tin-sulphide deposits were developed here by open and closed methods. The mining industry in the Solnechny district has operated since 1957 till 2005. There were two factories and three tailing dumps covering an area of 80.8 hectares, with the volume of processing waste to 41.5 million tons. Their material composition is as follows (%): vein quartz - 37.5, hornrock-sedimentary rock - 45, tourmaline - 12.1, and sulphides (galena and sphalerite, pyrite, pyrrhotite, arsenopyrite, chalcopyrite) - 3.8. They are characterized by the following useful components (g/t): Sn - 0.46, As - 0.629, Ag -1.227, Pb - 0.123, Zn - 0.094, Bi - 0.03.

In 1941 - 2001, in Kavalerovsky District there were six mines and four processing plants. The region has five tailing dumps with a total area of 17.7 ha, where 37.72 million tons of tailings have been accumulated. They include pyrite, pyrrhotite, galena, sphalerite, arsenopyrite, chalcopyrite, quartz, fluorite, tourmaline, chlorite and other minerals. Quantitative and semi-quantitative spectral analyses of samples showed that the ore elements content in them varies within the following limits (%): Sn - 0.04-
0.10; Cu - 0.0062-0.2600; Pb - 0.0039-0.0760; Zn - 0.08-1.00; As - 0.01-0.05; N - 0.0014-0.0033; Co - 0.0002-0.0009; V - 0.0043-0.0100; Ag - 0.0003-0.0030; Ga - 0.0011-0.0016; V - 0.01-0.05; Bi - 0.0001-0.0003; Sr - to 0.01; Ca - to 0.1 [25].

The researches have revealed that the technical state of investigated tailing dumps has appeared to be emergency, here, the level of safety is dangerous. The breaches of the following federal laws provisions were revealed: "About safety of hydraulic facilities (HF)", "About atmospheric air protection", "About production and consumption wastes", "About environment protection", and also requirements of "Rules of safety of HF accumulators of liquid and industrial wastes", normative and instructive documents of Gosgortekhnadzor (Federal Mining and Industrial Inspectorate) of Russia, Water and Land Codes of the Russian Federation. Thus, no measures have been developed to ensure industrial safety, subsoil and environmental protection and safety of hydraulic facilities (HF) for the period of work suspension at hazardous production facilities here.

Closed mining enterprises did not comply with the instructions of supervisory authorities to eliminate violations of technological and environmental safety requirements. The fencing dam of the tailing dumps was destroyed and their repair has not been carried out. Sludge pipe lines, recycled water pipes and the recycling station equipment were dismantled and spontaneous runoff and washing out of contaminants into the river net takes place. There is no monitoring of the tailing dump safety in accordance with the regulatory requirements. The intense dust pollution of the environment occurs, because no measures are taken to reduce dust pollution of the tailing dump surface and air pollution by reclamation of the tailing dump surface.

Under specific local meteorological conditions, the surface of the tailings dumps has been exposed to wind and water erosion over the years and is becoming an intensive source of ecosystem dust pollution as it contains less than 2 mm particles with high content of toxic components. Here, in the pond and intermediate zones, for example, the closed mining enterprise Solnechny GOK, a dense network of erosion potholes and scouring pits, more than 1 m deep and 0.3 - 1.2 m wide, which pass into ravines, was revealed. This is the result of the extreme natural processes development in recent years, namely, intensive heavy rainfall in the autumn of 2008 and during June-July 2009, due to the monsoon climate in the region under study. An equally important factor was a tailing dump surface slope of more than 3° from the beach zone to the pond surface. In addition, the slopes of the dam are also subject to erosion processes.

3.2. Risks of technogenic impact contributing to intensive pollution of the ecosphere

Conditions for the emergence of environmental risk from technogenic pollution, such as atmospheric air, are: the presence of a source of risk, including concentration of the pollutant harmful to the population and biota [26]. Besides, their presence in the impact zone and the ways to transfer the harmful impact from the source to a living organism are important. In this case, the main factor is the identification of priority objects of sources of crisis situations risk causing intensive technogenic environment pollution. Based on the information of the negative impact on ecosystems of mineral processing waste stockpiled in tailings dumps, closed mining enterprises Solnechny GOK and Khustalnensky GOK, a conclusion was made that among the main sources of crisis situations are the following:

1) tailing dumps, processing plants and settling tanks abandoned as a result of the bankruptcy of mining enterprises; 2) physical wear and tear and unreliability of the main technological equipment used in the last century. 3) low level of ecologization of processes, e.g. discharge of mine water and liquid waste, processing and tailing wallrock dump waste, when insufficiently treated effluents were discharged into water bodies; 4) application of outdated technologies and technological processes; 5) weakening of attention to environmental protection, reduction of the volume and efficiency of environmental protection activity by managers and nature protection services of mining enterprises operated in the last century; 6) imperfection of the environment legislation and the current system for environment pollution payments; 7) a touchy subject is the lack of demand for available scientific and technical developments, lack of incentives for their implementation and application in mining.
Thus, the aforesaid indicates that mining activities are potentially dangerous [27, 28] and there is always a probability of risks, including negative technogenic impact, leading to intensive pollution of environmental objects from tailing dumps wastes and increase of population morbidity rate. Thus, finely dispersed toxic dust rises from their surface to the air, forms vortexes and then precipitates on the soil. In addition, it has been established that atmospheric precipitation, dissolving a large number of toxic substances in itself, forms technogenic flows [29, 30], which is a negative factor for the soil-plant cover.

The problem is complicated by the fact that as a result of increasing solid waste sedimentation on the soil, its properties and composition are deteriorating at an increasing rate. The results obtained show that the heavy metals content in the studied soils and waters is by ten folds higher than the background indicators and MAC. Technogenic soils located near the tailings dumps are characterized by extremely high concentrations of HM and As (from 31 to 300 mg/kg), exceeding, for example, MAC from 1.5 to 15 and more times. Higher vegetation within the limits of the investigated tailing dumps impact accumulates the significant amounts of pollutants (Zn, Cu, Pb, etc.). It was revealed that technogenic pollution with compounds of heavy metals and arsenic in soils and vegetation even at a long distance from the location of technogenic formations storage (tailing dumps waste), exceeding the regional background indicators from 2 to 6 times and more.

Tables 1 and 2 show the calculation of the level of soil contamination with heavy metal compounds by a single factor pollution index (PI) and pollution load index (PLI), by the methods [22], within the limits of waste impact at the closed Solnechny GOK and Khrustalnensky GOK.

**Table 1.** Calculation of the pollution level according to the one-factor pollution index and the soil pollution load index within the boundaries of the impact of the closed mining enterprise Solnechny GOK.

| Object name          | Co    | Cu   | Zn   | As   | Mo   | Sn   | Hg   | Pb   | PI   | PLI |
|----------------------|-------|------|------|------|------|------|------|------|------|-----|
| Solnechny GOK tailing dump | 13.5  | 187.1| 16.2 | 59.0 | 11.8 | 12631.9| 343.9| 330.1| 119.2|     |
| 1 km from tailing dump  | 2.2   | 10.0 | 5.6  | 7.9  | 5.1  | 2008.9 | 231.4| 45.8 | 22.6 |     |
| 2 km from tailing dump  | 2.3   | 28.6 | 8.2  | 5.3  | 4.0  | 2135.0 | 116.8| 43.9 | 21.8 |     |
| 3 km from tailing dump  | 1.4   | 15.8 | 7.6  | 2.0  | 3.2  | 1216.3 | 30.9 | 74.3 | 14.8 |     |

**Table 2.** Calculation of the pollution level according to one-factor pollution index and pollution load index within the limits of impact of closed mining enterprise Khrustalnensky GOK.

| Object name          | Cr    | Co   | Ni   | Cu   | Zn   | As   | Sb   | Pb   | PI   | PLI |
|----------------------|-------|------|------|------|------|------|------|------|------|-----|
| Khrustalnensky GOK tailing dump | 2.5   | 1.9  | 2.7  | 45.7 | 6.0  | 159  | 56.4 | 10.4 | 11.6 |     |
| 1 km from tailing dump | 2.0   | 1.9  | 2.4  | 44.5 | 5.3  | 133.8| 42.8 | 10.0 | 10.3 |     |
| 2 km from tailing dump | 1.7   | 1.4  | 2.1  | 16.8 | 2.8  | 15.9 | 8.4  | 5.9  | 4.3  |     |
| 3 km from tailing dump | 1.2   | 0.6  | 1.7  | 5.9  | 1.2  | 5.0  | 3.3  | 2.8  | 2.1  |     |
Figure 1. Calculation of geoaccumulation in soil within the waste impact boundaries of the closed mining enterprises Khrustalnensky GOK (KhGOK) and Solnechny GOK (SGOK).

According to the Pollution Load Index (PLI), highly polluted soils in the study area near the tailings dams of Solnechny GOK and Khrustalnensky GOK (1-3 km) can be classified as very polluted. The highest figures are for arsenic compounds, especially near Solnechny GOK (SGOK).

Table 3 shows the results of calculation of the natural mobility index (NMI).

| Object name                          | Natural mobility indicator (NMIn) | Natural mobility index (NMI) |
|--------------------------------------|---------------------------------|-----------------------------|
|                                      | Cr     | Ni     | Cu     | Zn     | Sr     | Sn     | Hg     | Pb     |             |
| 3-d tailing dump of                  | 500.3  | 463.2  | 217.4  | 42.7   | 3.4    | 0.1    | 0.1    | 1.0    | 8.7         |
| Khrustalnensky GOK                   |        |        |        |        |        |        |        |        |             |
| Tailing dump of                      | 5.4    | 13.3   | 631.2  | 12.9   | 1.3    | 248.6  | 1.0    | 67389.6 | 43.3        |
| Solnechny processing plant          |        |        |        |        |        |        |        |        |             |
| Gorny settlement, 3-d                | 2.5    | 7.8    | 488.3  | 8.1    | 1.0    | 1.0    | 1.0    | 53657.5 | 16.0        |
| tailing dump                         |        |        |        |        |        |        |        |        |             |

According to the calculations (Table 3), the assessment of heavy metal compounds mobility in water sources near the tailings dumps is very high, especially near the Solnechny GOK tailings dump, where the Kholdomi River discharges into the Silinka River, carrying its waters into the Amur River having biosphere importance.

3.3. Socio-ecological risks associated with the population living at the technogenically polluted territory

The Law of the Russian Federation "On Industrial Safety of Hazardous Industrial Facilities" adopted in 1997 [31] provides that the enterprise, which is a source of high hazard, is obliged to provide the measures to protect the population and environment from dangerous impacts. In this regard, there is a need to assess social and environmental risks, which involves not only identifying and predicting the onset of adverse effects, but also the damage to public health and environment components, as well as their elimination. In addition, it is also envisaged to obtain quantitative and qualitative indicators of crisis situations, as well as accidents prevention.

Social and environmental risk assessment includes the following stages: 1) identification of emergency situations related to technogenic pollution of the environment and assessment of environment damage to human health; 2) estimation of the cost of work for full elimination of environmentally significant consequences caused by the crisis situation.

Our research [32-34] shows that the population of mining settlements lives in conditions of constant exceeding of normative indicators of air pollutants, within the limits of the impact of mineral processing...
wastes stored in tailing dumps. The result of this action is a response in the form of physiological shifts and development of environment caused diseases. Children's population requires special attention, as children are most vulnerable and sensitive to chemical agents in general [35].

The obtained data on the environment state on the basis of calculated hazard coefficients (HQ) and hazard index (HI) for contaminants (sulphur dioxide and heavy metal compounds) show morbidity growth with increase of technogenic pollution level of ecosphere. Interaction between the level of pollution by carcinogenic substances in the habitat and the occurrence of malignant tumors (MT) was identified. The hazard coefficient (HQ) calculated by formula [35] for groups of substances acting on the nervous system (Pb, Mn and Co) is equal, respectively: 80.7; 3.6 and 3.9, which indicates a high level of environment pollution.

Calculation of the hazard index (HI) for the following substances negatively affecting the respiratory system: suspended particles, sulfur dioxide, as well as copper, chromium compounds shows that in the study area its value reaches a significant value (HI = 71.88). Lead, manganese and cobalt compounds with a hazard index of 5.94 ranks second in terms of risk exposure. A close correlation between the index of carcinogenic compounds, for example, Sb and respiratory diseases with such Sb and neoplasms has been established. [32-34].

The current situation during the ore deposits development in the FEFD predetermines the need to develop the principles for ensuring the environmental safety of tailing dumps containing tin processing toxic waste. The researches have allowed to offer the following principles of normal functioning of technogenic objects within the impact limits of the closed mining enterprises Solnechny GOK and Khrustalnensky GOK:

1. Rational safety as necessity of maximum economically justified reduction of probability of emergency ecological situations and scope of their consequences in the conditions of closed mining enterprises; 2. Preservation of the most important element of quality of life - favorable environment for biota and health of population of mining settlement in the conditions of closed mining enterprises; 3. Accounting of various natural hazards and anthropogenic impact on the ecosphere of tailing dumps (balanced risk principle); 4. (acceptable risk principle). In international practice, this principle is known as the ALARA (As Low Reasonable Achievable) principle - that is, as low as reasonably achievable.

Based on the principles, the following measures have been proposed to ensure environmental safety of tailing dumps containing toxic wastes of tin processing within the limits of their impact in conditions of closed mining enterprises Solnechny GOK and Khrustalnensky GOK:

1. Creation of economic mechanism to reduce the risk of environmental damage from emergency situations; 2. Creation of a new technology for remediation of the surface of tailing dumps using an innovative approach (bioremediation), novelty of which is confirmed by the patents of the Russian Federation (2018-2019, etc.) [36, 37] and its implementation to reduce the negative impact on the environment; 3. Development of a system of mining environmental monitoring of the state of environment components within the limits of the impact of tailing dumps of closed mining enterprises; 4. Creation of a forest protection belt around the tailing dump and maximum landscaping of the territory of mining settlements to prevent anthropogenic pollution of the ecosphere; 5. Carrying out medical and environmental survey of the population to improve their health in connection with the formation of environmentally caused diseases.

4. Conclusion

1. High ecological toxicity of wastes of the closed mining enterprises Solnechny GOK and Khrustalnensky GOK is established, which undoubtedly promotes intensive pollution of objects of environment and increase of morbidity of the population of mining settlements in the FEFD; 2. The indicators and the factors which have become the reason of the crisis phenomena leading to ecological risks of storage of the saved up wastes of processing of mineral raw materials as a result of the past activity of the closed mining enterprises are revealed; 3. The level of pollution of compounds is estimated. New technologies of reclamation of the tailing dumps surface, containing mineral processing toxic wastes, novelty of which is confirmed by the Patents of the Russian Federation, are created.
5. References

[1] Svinboeva O N, Nogovitsyn R R 2017 Prospects for the revival of tin industry in the Republic of Sakha (Yakutia) Problems of the modern economy 3(63) pp 183-186

[2] Krupskaya L T, Grekhnev N I, Zvereva V P, Novorotskaya A G, Derbentseva A M, Starozhilov V T 2009 Ensuring environmental safety of sources of environmental risk at tin enterprises in the south of the Far East Bulletin of the Peoples' Friendship University of Russia. Series: Ecology and Life Safety 4 pp 81-88

[3] Pinaev V E, Chernyshev D A 2017 Elimination of accumulated environmental damage – organizational and legal aspects Monograph (M.: World of Science) 136 p

[4] Decree of the Government of the Russian Federation of November 17, 2008 N 1662-r (as amended on September 28, 2018) “On the Concept of Long-Term Social and Economic Development of the Russian Federation for the Period Until 2020” (together with the “Concept for Long-Term Social and Economic Development of the Russian Federation for the Period Until 2020”)

[5] Gegiev K A, Sherkhov A Kh, Gergokova Z Zh, Anakhaev K K 2018 Ecological problems of the Tyrnyauz tailing dump on the Gijgit river Bulletin of MGSU 13 Vol. 11 pp 1386-1394 DOI: 10.22227/1997-0935.2018.11.1386-1394

[6] Ivanova O A, Kulina T S 2016 Environmental consequences of tungsten ore mining (for example, Zakamas district of the Republic of Buryatia). Proceedings of the Siberian Branch of the Section of Earth Sciences of the Russian Academy of Natural Sciences 3(56) pp 95-101

[7] Pashkevich M A, Strizhenok A V 2012 Assessment of anthropogenic load in the area of the storage of apatite-nepheline ore dressing waste. Bulletin of Tula State University. Earth sciences 2 pp 35-41

[8] Gurbanov A G, Bogatikov O A, Gazeev V M, Leksin A B, Vinokurov S F, Karamurzov B S, Shevchenko A V, Dolov S M, Dudarov Z I 2015 Geochemical evaluation of environmental conditions in the area of activity of the tyrnyauz tungsten–molybdenum plant (Kabardino-Balkaria, north Caucasus): sources of environment contamination, impact upon neighboring areas, and ways for recovery Doklady Earth Sciences Vol. 464 1 pp 967-971

[9] Vinokurov S F, Gurbanov A G, Bogatikov O A, Gazeev V M, Shevchenko A V, Dolov S M, Karamurzov B S, Leksin A B, Dudarov Z I Contents, seasonal variations, and forms of migration of major and minor elements in surface waters in the area of the Tyrnyauz Tungsten–Molybdenum combine (TTMC) and adjacent areas (Kabardino-Balkarian republic, Russian Federation) and actions for recovery of the ecological environment Doklady Earth Sciences Vol. 467 2 pp 346-349

[10] Chigoeva D N, Kamanina I Z, Kaplina S P 2018 The content of heavy metals in watercourses in the region of the Unal tailings and the Ardon River South of Russia: ecology, development Vol. 13 2 pp 113-122 DOI: 10.18470/1992-1098-2018-2-113-122

[11] Kachor O L, Sarapulova G I, Bogdanov A V 2019 Search for a method of neutralizing man-made mining waste contaminated with arsenic Collected scientific articles of the IX International scientific conference pp 14-17

[12] Salas-Luévano M A, Mauricio-Castillo J A, González-Rivera M L Accumulation and phytostabilization of As, Pb and Cd in plants growing inside mine tailings reforested in Zacatecas (Mexico) Environ Earth Sci 76

[13] Soltani N, Keshavarzi B, Moore F 2017 Distribution of potentially toxic elements (PTEs) in tailings, soils, and plants around Gol-E-Gohar iron mine, a case study in Iran Environ Sci Pollut Res. 24 pp 18798-18816

[14] Abdellah E I Azharia, Ali Rhoujjatia, Moulay Laârabi El Hachimi, Jean-paul Ambrosi 2017 Pollution and ecological risk assessment of heavy metals in the soil-plant system and the sediment-water column around a former Pb/Zn-mining area in NE Morocco Ecotoxicology and Environmental Safety Vol 144 pp 464-474
[15] Antonio Romero, Isabel González, José María Martín, María Auxiliadora Vázquez, Pilar Ortiz 2015 Risk assessment of particle dispersion and trace element contamination from mine-waste dumps Environmental Geochemistry and Health Vol 37 pp 273-286

[16] May I V, Kley S V, Vekovshchina S A 2019 Assessment of impact of accumulated environmental damage to the quality of soil, surface and groundwater, agricultural products resulted from the mining enterprise IOP Conf. Ser.: Earth Environ. Sci. 315 062024

[17] Zhigang Hu, Chensheng Wang, Keqing Li & Xinyou Zhu 2018 Distribution characteristics and pollution assessment of soil heavy metals over a typical nonferrous metal mine area in Chifeng, Inner Mongolia, China Environmental Earth Sciences Vol. 77 638

[18] Sung-Min Kim, Jangwon Suh, Sungchan Oh, Jin Son, Chang-Uk Hyun, Hyeong-Dong Park, Seung-Han Shin, Yosoon Choi 2016 Assessing and prioritizing environmental hazards associated with abandoned mines in Gangwon-do, South Korea: the Total Mine Hazards Index Environmental Earth Sciences Vol. 75 369

[19] Rosario García-Giménez & Raimundo Jiménez-Ballesta. Mine tailings influencing soil contamination by potentially toxic elements Environmental Earth Sciences Vol. 76 51

[20] Gbadebo A M & Ekwue Y A 2014 Heavy metal contamination in tailings and rocksamples from an abandoned goldmine in southwestern Nigeria Environmental Monitoring and Assessment Vol 186 pp 165-174

[21] Mayra Peña-Ortega, Rafael Del Río-Salas, Javier Valencia-Sauceda, Héctor Mendivil-Quijada, Christian Minjarez-Osorio, Francisco Molina-Freaner, Margarita de la O-Villanueva & Verónica Moreno-Rodríguez Environmental assessment and historic erosion calculation of abandoned mine tailings from a semi-arid zone of northwestern Mexico: insights from geochemistry and unmanned aerial vehicles Environmental Science and Pollution Research Vol. 26 pp 26203–26215

[22] Mari Luz García-Lorenzo, Elena Crespo-Feo, Jose María Esbrí, Pablo Higuera, Patricia Grau, Isabel Crespo, Ramón Sánchez-Donoso 2019 Assessment of Potentially Toxic Elements in Technosols by Tailings Derived from Pb–Zn–Ag Mining Activities at San Quintín (Ciudad Real, Spain): Some Insights into the Importance of Integral Studies to Evaluate Metal Contamination Pollution Hazards Minerals 9(6) 346

[23] Jiang F, Ren B, Hurthouse A 2019 Distribution, source identification, and ecological-health risks of potentially toxic elements (PTEs) in soil of thallium mine area (southwestern Guizhou, China) Environ Sci Pollut Res. 26 pp 16556-16567

[24] Müller G 1969 Index of geoaccumulation in sediments of the Rhine river GeoJournal 2 108-118

[25] Zvereva V P 2007 Man-made waters of tin ore deposits in the Far East Geocology. Engineering geology. Hydrogeology. 2007 1 pp 51-56

[26] Mamaev Yu A, Krupskaia L T, Grekhnev N I, Morin V A, Krupsky A V 2008 Ensuring environmental safety of sources of risk of crisis situations from mining enterprises in the Amur region Mountain Information and Analytical Bulletin (scientific and technical journal) pp 252-259

[27] Belyaev A M 2011 Assessment of the ecological and geochemical hazard of mineral deposits Bulletin of St. Petersburg University. Earth sciences Is. 3 pp 43-48

[28] García-Giménez R, Jiménez-Ballesta R 2017 Mine tailings influencing soil contamination by potentially toxic elements Environ Earth Sci. 76 51

[29] Tsydypov V V, Zhamseueva G S, Zayakhanov A S, Starikov A V, Dementieva A L, Naguslaev S A, Balzhyan T S, Sungrapova I P 2019 The influence of the technogenic sands of the tailings of the Dzhidinsky tungsten-molybdenum plant on the content of fine and submicron aerosol fractions in the atmosphere of the city of Zakamensk The successes of modern science 4 pp 81-86

[30] Dragana Randelović, Jelena Mutić, Prvoslav Marjanović, Tamara Đorđević, Milica Kašanin-Grubin 2020 Geochemical distribution of selected elements in flotation tailings and
soils/sediments from the dam spill at the abandoned antimony mine Stolice, Serbia. "Environmental Science and Pollution Research" Vol. 27 pp 6253-6268.

[31] Federal Law of July 21, 1997 N 116-ФЗ (as amended on July 29, 2018) “On Industrial Safety of Hazardous Production Facilities”

[32] Rastanina N K, Krupskaya L T 2008 On the role of environmental factors in the study of the health of the population of mining villages in the south of the Far East. "Ecology and industry of Russia" 12 pp 56-57.

[33] Krupskaya L T, Melkonyan R G, Zvereva V P, Rastanina N K, Golubev D A, Filatova M Yu 2018 The environmental hazard of waste accumulated by mining enterprises in the Far Eastern Federal District and recommendations for reducing the risk of environmental disasters. "Mountain Information and Analytical Bulletin (scientific and technical journal)" 12 pp 102-112.

[34] Krupskaya L T, Rastanina N K 2007 An assessment of the public health risk associated with air pollution in the tailings area of the TsOF Solnechny GOK. "Mountain news and analytical bulletin" 15 pp 318-323.

[35] Kurolap S A, Mamchik N P, Klepikov O V 2006 Health risk assessment for technogenic pollution of the urban environment (Voronezh: Voronezh state. Univ.)

[36] Krupskaya L T, Ischenko E A, Golubev D A, Kolobanov K A, Rastanina N K 2019 Patent of the Russian Federation No. 2707030 Composition for reducing dust load on the ecosphere and the restoration of the surface of the tailings.

[37] Krupskaya L T, Rastanina N K, Golubev D A, Filatova M Yu 2018 Patent of the Russian Federation No. 2672453 Composition for dust suppression for the restoration of the surface of the tailings.