ЕКОЛОГІЧНА БЕЗПЕКА, ОХОРОНА ПРАЦІ

УДК 66.022.63:502.36

I.O. Nikolaieva[1],
D.V. Rudakov[2], Dr. Sci. (Tech.), Prof.

1 – Innovation Center "Ecosystem", Kiev, Ukraine, e-mail: ecoauditdnepr@yandex.ua
2 – State Higher Educational Institution "National Mining University", Dnipropetrovsk, Ukraine, e-mail: dmi3rud@mail.ru

DEVELOPMENT OF A CHECKLIST FOR IMPROVEMENT OF TAILINGS SAFETY

І.О. Ніколаєва[1],
Д.В. Рудаков[2], д-р техн. наук, проф.

1 – Інноваційний центр „Екосистема", м. Київ, Україна, e-mail: ecoauditdnepr@yandex.ua
2 – Державний вищий навчальний заклад „Національний гірничий університет", м. Дніпропетровськ, Україна, e-mail: dmi3rud@mail.ru

РОЗРОБКА КОНТРОЛЬНОГО СПИСКУ ДЛЯ ПІДВИЩЕННЯ БЕЗПЕКИ ХВОСТОСХОВИЩ

Purpose. Justification and development of the Checklist concept applied for assessment and improvement of tailings management facilities (TMFs) safety.

Methodology. To develop the Checklist for tailings we used the test question method that allows evaluating all the important aspects of TMF safe operation. This document includes questionnaires with standardized options of answers and a special procedure for overall and differential (categorial) evaluation of TMF safety level.

Findings. The structure and procedure for applying the TMF Checklist have been designed. It includes questionnaires for prompt (basic) and detailed evaluation of the safety level of such facilities, their ongoing monitoring, and evaluation of abandoned TMFs. The method developed is able to quantify the TMF safety level regarding credibility of the information available. The Checklist includes the catalogue of measures recommended to remedy inconsistencies with safety requirements discovered during an inspection.

Originality. For the first time, we have developed a holistic approach to the evaluation of the safety of tailings as hazardous facilities as well as the detailed algorithm of their audit. This includes the answers to Checklist questions, their quantitative assessment and prescription of the most powerful solutions in the Measure Catalogue.

Practical value. The Checklist may be useful for state environmental and emergency inspectors, eco-auditors and TMF operators as a tool to assess the safety level and take protective and preventive measures at the tailings. The Measure Catalogue of the Checklist contains a list of actions based on the international best practices in mining and rehabilitation technologies. The Checklist designed is featured as the spreadsheet with hyperlinks, which facilitates its practical use.

Keywords: *Tailings, Checklist, safety, evaluation, Measure Catalogue*

Introduction. Tailings Management Facilities (TMFs) storing large amounts of mining wastes pose serious threats to humans and the environment, especially if they improperly designed, constructed, operated or managed [1]. In case of high toxicity of stored materials, inappropriately secured and located near residential areas they might be attractive goals for terrorist attacks aiming to cause large damage to various infrastructures and local communities.

The total amount of tails in TMFs around the world reached some hundredth billion tons, among them more 25 billion tons in Ukraine only. Commonly mining wastes are stored in old or abandoned facilities. The accidents at TMFs may frequently lead to long-term water and soil pollution, damage biota and have negative after-effects to human health. Failures may result in uncontrolled spills of tailings, dangerous release of hazardous substances.

The negative impacts of such incidents on humans and the environment and severe transboundary consequences have been demonstrated by recent accidents in Europe. Recently they occurred at tailings in Baia Mare, Romania, aluminium sludge tailings in Kolontar, Hungary, at the Talvivaara Mining Company in Finland; and at the red mud tailings near the city of Nikolaiev, Ukraine.

Although TMFs are operated with strengthening requirements in many countries, their safety needs further improvement taking into account climate change, growing geological risks as well as the advances in remediation technologies and techniques in mining [2, 3]. The general strategy combining advanced approaches to evaluation of

TMF safety would have many organizational benefits in different countries.

Currently, the regular inspections of TMF are conducted according to national regulations, often without systematic approach or paying no attention for international standards and best engineering solutions in sustainable mining and environment restoration. Comparative analysis of hazards and risks created by TMF in different countries of Europe shows the need for a common approach to evaluating the safety and, if possible, harmonization of the regulatory framework. As a rule, ongoing efforts are focused on checking some aspects of TMF performance (EIA, monitoring, dam conditions etc.). Overall evaluation of the safety level, prescription of protective and preventive measures based on BAT is still not the common practice.

To address this challenge, German Federal Environmental Agency has initiated a project aiming at the development of TMF Checklist on the base of the experience of Ukrainian TMF with the involvement of Ukrainian and international experts (www.tmf-ukraine.org). The Checklist objectives can be briefly summarized as:

- Efficient and reliable evaluation of the TMF safety level with using modern software tools in the way easy to understand and apply.
- Elaboration of the procedure of prescribing protective and preventive measures to remedy non-compliances between current TMF conditions and modern safety standards.

TMFsas typical geotechnical systems consist of both natural and technical elements, closely interrelated and functioning as a single entity. TMFs include the elements of three types that are:

- created by man (tailing dam, retention pond, facilities for transporting tails, drainage and sewage system, impervious screens and shields);
- of natural origin (soils, groundwater, surface water bodies, and soils within the TMF site);
- of mixed origin or changed during the construction and operation (tails, lagoon, impoundment bed).

All these elements have to be properly addressed by the Checklist developed. Proper management plays the crucial role for maintaining TMF safety. To improve the management the inspecting bodies, TMF operators, and independent ecological auditors need in the modern tool to adequately and realistically evaluate, to which extent the TMF meet modern safety requirements as well as to take appropriate actions in terms of public safety. The Checklist has to account properly for the TMF specifics as a multi-feature object combining technical, natural and mixed-origin elements.

The proposed TMF Checklist is theoretically based on the test question method, developed by D. Polia, A.F. Osborne, G.Ya. Bush and others. The method requires answering the questions specially selected to identify the main problems of the studied case and come to the most powerful solutions. The test question method is used for development of inventions, improvement of technologies, products, organizational structures, and to search for new business ideas as well. Test questions formulated as a Checklist may have complicated hierarchy structured in several levels.

The advantages of the elaborated Checklist are that:

- all Checklist users (inspection, auditors and operators) use the same procedure for checking TMF;
- TMF operators know non-compliances of the TMF with safety requirements prior to check and can start getting them fixed in advance;
- all Checklist users work with the same Measure Catalogue that accumulated best available technologies in sustainable mining.

In a more general context a checklist is an example of expert systems increasingly applied for controlling complex technical devices and facilities. A modern expert system is commonly a computer system capable of partially replacing professional experts solving a problem situation. Expert systems had been developed by researchers in 1970s to create artificial intelligence; since 1980s commercial applications appeared. Their examples include the selection of employees, disease diagnosis by symptoms, creating logical structures in programming using Wizard tools, mapping, military activities, electronic networks etc. Expert systems are able to automate the process of monitoring and making decisions, which would reduce negative impacts of the human factor (subjectivity, lack of skills etc.).

The main challenges in TMF Checklist design are:

1) optimization of structure and application procedure;
2) selection of questions regarding to national practices and availability of documentation;
3) definition of categories to adequately characterize TMF conditions;
4) development of criteria to adequately evaluate the TMF safety level in details;
5) selection of measures to respond the typical problems at the TMF site.

Previous documents on TMF safety [4–8] addressed most of critical safety issues. However, many of them are very general and do not contain clearly structured protective and preventive measures. The document [1] being updated during last decade was used as the basis for the TMF Checklist in terms of the topics to be covered, general structure, and content.

This paper aims to highlight the basic principles of TMF Checklist design and adjustment for practical use and making this document an efficient toolkit to improve environmental safety in the areas affected by TMF.

Checklist structure and application. It is proposed to subdivide all the questions of TMF Checklist into four groups according to their purposes, criteria, and the level of details.

The first group of questions is intended for preliminary and prompt evaluation of the TMF safety level using available documentations of the TMF operator. A Checklist user can independently evaluate the TMF safety level in short period of time and then has to decide if there is the need for more detailed inspection of the TMF. One subgroup of the first question group focuses on company/enterprise documentation only; the other group is designed for the inspecting staff visiting the site.

If some non-compliances with relevant safety requirements are detected *the second group* of questions should be applied that aims to evaluate the TMF safety level in more

details. Thus, checking the TMF will require not only the available operator's documentation but also additional studies and tests clarifying and refining all TMF parameters involving external bodies with proven professional technical expertise.

The third group of questions addresses non-operated and abandoned TMF considered as the specific case.

The Checklist includes the recommendations for regular control the TMF safety level on-site under normal operation, as well as for facility inspections, education and training of inspectors.

The Checklist users of the first question group are competent authorities and state inspectors; the second and third question groups are intended for state inspectors and TMF operators.

Tailings elements are changing in course of TMF development. The risks and impacts of man-made elements are growing (increasing amount of tails, aging of technical devices including dam, drains, and pipelines); besides, natural elements are degraded. To address these issues many regulations on TMF operation adopted in different countries (EU, Australia, Canada, and Ukraine) discriminate the phases of TMF life-cycle (design, construction, operation, closure, and rehabilitation). Throughout the life-cycle the environmental inspection and TMF operators have to monitor TMF site conditions, control its environmental impacts as well as operation, staff qualification and preparedness to emergencies and accidents.

The TMF Checklist includes the number of questions related to public attitude and discussion of a new TMF project on the stage "Design"; thus developers must account for concerns of local communities (authorities, public, NGO etc.) during design and implementation of the project.

The workflow of Checklist application is shown in fig. 1.

Evaluation Principles and Measure Catalogue. There are a number of challenges in quantification of TMF conditions. Due to the complex nature of TMF the Checklist user has to frequently deal with "mixed" or "combined" hazards related to different elements of tailings. Thus, we have to apply different scales and combine the groups of criteria. In fact, the Checklist user evaluates how many failures of safety rules are detected; however, the user does not calculate the risks as such because they are based on damage likelihood and have to be evaluated using special techniques.

To provide the consistency of the evaluation procedure all answers to Checklist questions are unified. The positive answer ("Yes") is always interpreted as the maximum level of TMF safety for the evaluated criterion; the negative answer ("No") is considered as the minimum level, respectively. The positive answer is equivalent to the maximum possible numerical value in the accepted scale (3); the negative answer gives the zero value to the total sum.

The ambiguous answers "Mostly yes" and "Mostly no" has to be accepted if there is no sufficient information to give the definitive answer ("Yes" or "No"). The option "Mostly yes" is applied if a Checklist user does not have enough data or information to give the definitive answer ("Yes" or "No") but the user has more arguments to accept the positive answer "Yes" rather than "No". The option "Mostly no" is applied if a Checklist user does not have enough data or information to give the definitive answer ("Yes" or "No") but the user has more arguments to accept the negative answer "No" rather than "Yes". This approach allows the user be more flexible in giving the answers regarding the completeness of information.

Two kinds of evaluation for the TMF safety level are proposed. The overall safety level summarizes all answer contributions; it enables general assessment of TMF conditions and ranking the priority of interventions and remedial actions. The second kind of evaluation called "categorial" has been introduced to quantify the TMF safety on different categories of facility. The Checklist categories differentiate TMF evaluation in such aspects as: 1 – geology, climatic and terrain risks; 2 – TMF deposition, 3 – substances, 4 – dam and screens, 5 – transportation and infrastructure, 6 – water management, 7 – Environment Impact Assessment, 8 – Emergency plan, 9 – monitoring, 10 – protection measures, 11 – inspection and reporting, 12 – closure and rehabilitation strategy. Each question is assumed to be in one of these categories only.

"Safety" rank for the TMF Checklist is defined as an index quantifying how the parameters of all or single components and characteristics of the TMF meet the modern requirements of environmental and industrial safety. "Safety" rank is calculated by summing up the answer values.

"Credibility" rank for the TMF Checklist is defined as an index quantifying the sufficiency of data while calculating the "Safety" rank; it is calculated as the fraction of definitive answers ("Yes" or "No").

An evaluation point on the plot (fig. 2) shows how the TMF complies with safety requirements. The point tending to the right upper corner meets the higher safety level; in contrast, positioning the evaluation point in the lower left corner means the low level of TMF safety. The criteria quantifying the TMF safety level based on the ranks "Safety" and "Credibility" should unify different approaches to hazardous site assessment accepted in different countries. It is recommended to elaborate these criteria based on national practices and international experiences. Categorial evaluation is visualized in fig. 3.

The Measure Catalogue is likely the most important element of the Checklist. The Catalogue defines the procedure how to prescribe the most relevant measures to improve TMF safety regarding to local conditions. Specific parameters of these measures have to be established by either national documents or special tests and expert assessments.

The Measure Catalogue includes the list of actions to be taken in case of establishing partial or full non-compliances of TMF conditions with actual safety requirements. A Checklist user has to prescribe the appropriate action(s) per each problem detected at the TMF. The measures address all phases of TMF life-cycle and are grouped in such a way to solve specific problems detected while inspecting TMF; the measures are specified according to their priorities.

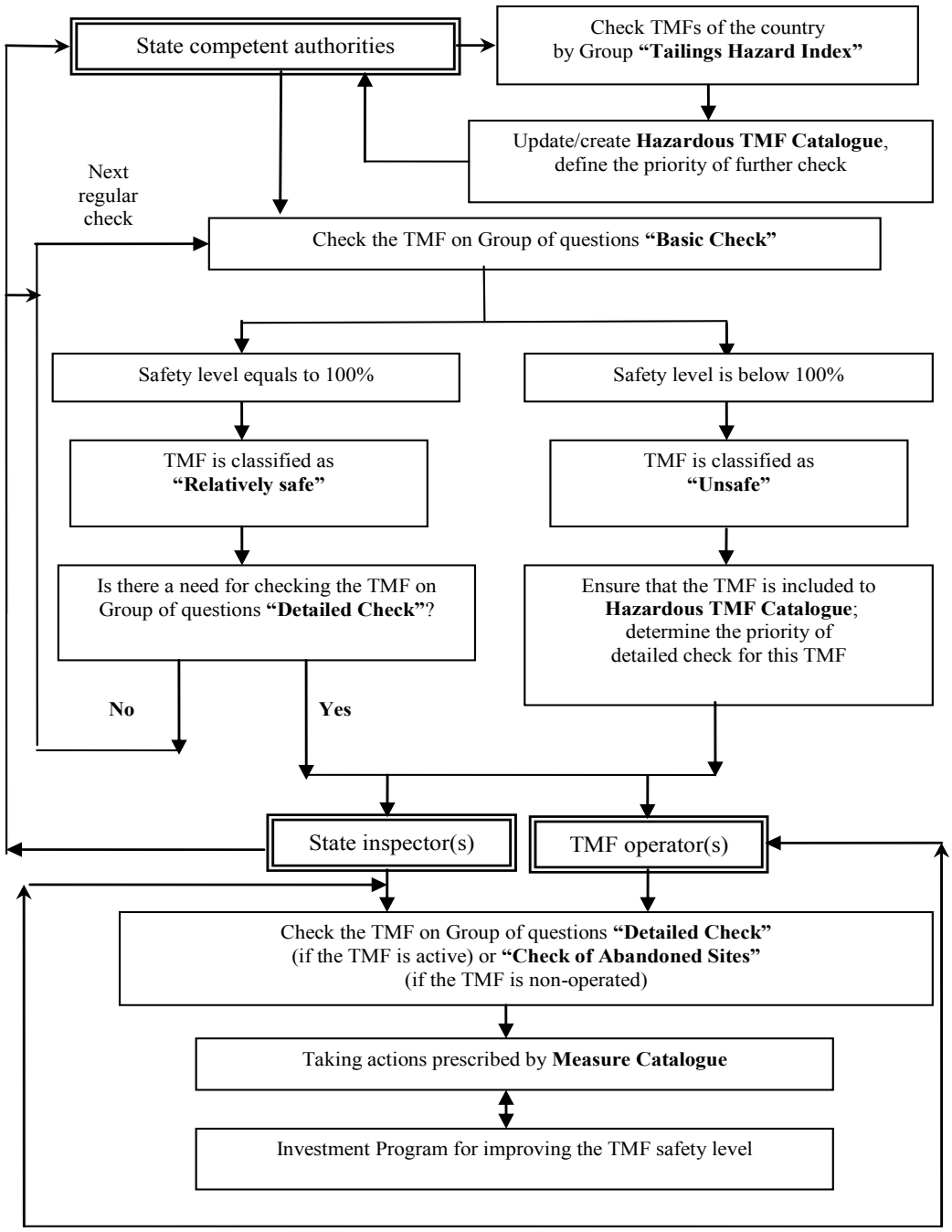

Fig. 1. Proposed workflow with the TMF Checklist

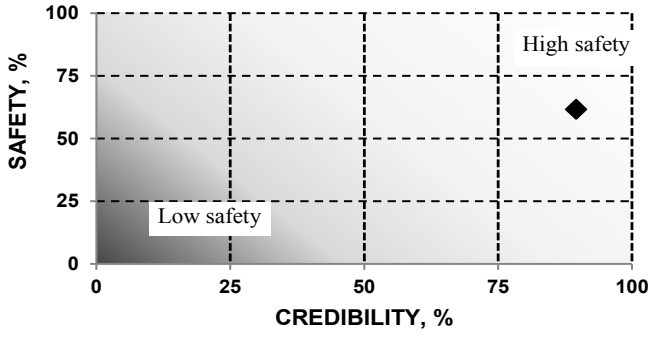

Fig. 2. Visualization of the categorial evaluation example for the TMF safety level

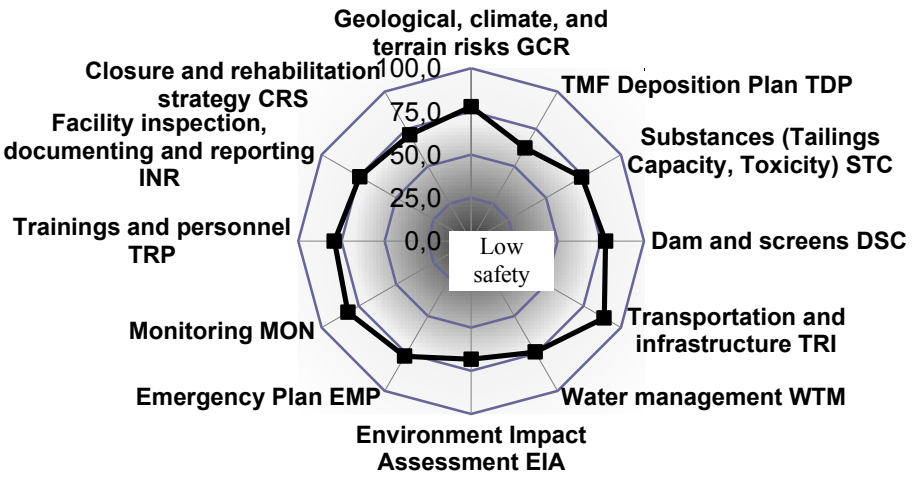

Fig. 3. Visualization of the categorial evaluation (in %) for the TMF safety level (categories and abbreviations)

A detected problem is defined in TMF Checklist as a clearly and briefly formulated partial or full non-compliance with regulatory documents, safety rules or requirements. Each question of the second group of the TMF Checklist refers to a certain problem in Measure Catalogue. One or more alternative actions are listed for each problem, which facilitates filling in the TMF Checklist.

Measure priority depends on urgency and costs of prescribed action(s) and can be defined as short-, mid-, and long-term. *Short-term measures* are generally low-cost technical and/or organizational measures or actions that the TMF operator is usually able to implement using the own resources [6]. The Checklist users have to discriminate short-term measures and Emergency plan actions; the latter are defined separately and must be agreed with local Emergency Ministry/Service departments.

Mid-term measures are technical and/or organizational measures aimed to improve tailings safety taking into account the economic capacity of the company operating the TMF. The measures have to be thoroughly studied and assessed by "cost-effectiveness" criteria. *Long-term measures* have to ensure technical transformation of the inspected TMF regarding the implementation of European standards in industrial and environmental safety. These measures are mostly applicable to closure and rehabilitation phases of the TMF life-cycle.

As the basis for Measure Catalogue both international and national documents have been used [2]. These have summarized best practices on safe operation and rehabilitation of TMF sites and other mining facilities. It will enable further permanent improvement of Measure Catalogue thro-ugh inclusion of effective relevant measures recommended by national documents of European and other countries.

The TMF Checklist is designed as a spreadsheet in MS Excel, which provides automatic calculation of the safety level and hyperlink transition from questions to recommended measures listed in other tabs of the same Excel file. In future, the Checklist file may be re-structured as a geo-information system including graphical images and previous inspection reports.

Discussion and conclusions. The TMF Checklist is proposed as a toolkit to improve safety in the areas affected by tailings. In case of Checklist implementation a number of law regulatory and organizational mechanisms will be activated, which will eventually bring the benefits to public safety.

1.The TMF Checklist approval on the governmental level will be followed by primary check of all TMF and creating the country's catalogue of TMF. This list has to rank the checked TMF according to their safety and hazards; thus, prioritize further actions.

2. The TMF Checklist based on best available practices imposes unified strict requirements both to TMF operators and state inspectors. Sometimes they are not aware of all TMF-related hazards as well as of international safety requirements; they frequently use regulatory documents that are often not correlated each other and not covering all aspects of TMF operation. For this reason, both TMF operator staffs and state ecological inspectors will enhance their qualification because of systematic of TMF Checklist application.

3. The TMF Checklist clearly specifies that the TMF operator has to inform local population in case of emergencies and accidents. Discussions with local communities in the form of public hearings, liability to consult with local authorities and receive their endorsement per a TMF project will be mandatory according to the TMF Checklist. This is surely vastly important for the countries lacking of such practices and creates the preconditions of broader public engagement to improvement of safety in mining areas. According to Checklist requirements, the operator has to keep much strictly safety rules and develop infrastructures near tailings, carry out geotechnical and environmental monitoring according to modern standards.

4. The TMF Checklist attempts to unify the evaluation procedure of tailings safety, which will improve the inconsistent approach still applied in some countries to evaluate and deal with TMF of different types.

5. The TMF Checklist requires obligatory development of closure and rehabilitation plans for all TMF, both operated and designed. Regular conducting the trainings for the TMF personnel should be mandatory, which will enhance staff preparedness to emergencies and accidents.

6. Some relevant preventive short-term and mid-term measures from Measure Catalogue can be recommended to inclusion into emergency plans required at all TMF. This may reduce the risks of accidents and emergencies at tailings most dangerous to local population.

7. Systematic application of the TMF Checklist in different countries will contribute to better understanding the risks induced by complex geotechnical systems. Regular inspections and safety reporting will generate more valuable data on TMF operation and safety. Thus, in course of time the Checklist may be transforming into a widening database or GIS to be used by authorities for decision making on priority of remedial actions in environment restoration and public safety.

The developed TMF Checklist addresses the challenge of improving hazardous site management and public safety in TMF affected areas. The applied method takes into proper account advanced practices in the field of hazardous site assessment and restoration.

Systematic application of TMF Checklist will increase the credibility of TMF safety assessment. All groups of TMF Checklist questions and Measure Catalogue are combined in one spreadsheet file, which facilitates the Checklist use.

If regularly applied, the TMF Checklist ensures credible evaluation of TMF conditions related to safety of both TMF and local population. Putting the TMF Checklist into practice will increase the level of understanding the hazardous sites, local community awareness on related risks.

Acknowledgment. The authors express their personal gratitude to Mr. G. Winkelmann-Oei (German Federal Environmental Agency) for initiating the idea of TMF Checklist development. We thank Mr. J. Vijgen (IHPA, Denmark) for cooperative support, comprehensive communication, and exchange of ideas. Besides, we are gratitude to Prof. G. Shmatkov and Mr. Yu. Shestak for fruitful cooperation.

References / Список літератури

1. *Safety Guidelines and Good Practices for Tailing Management Facilities*, (2014), UNECE.

2. *Reference Document on Best Available Techniques for the management of tailings and waste-rock in mining activities*, (2004), Joint Research Center of EU Commission.

3. Peck, P.C. (2005), "Mining for Closure: Policies and Guidelines for Sustainable Mining Practice and Closure of Mines", *UNEP, UNDP, OSCE, NATO*, Geneva.

4. *Checklisten für Untersuchung und Beurteilung des Zustandes von Anlagen mit wassergefährdeten Stoffen und Zubereitungen*, (2006), Umweltbundesamt Deutschland.

5. *Tailings Management. Leading Practice Sustainable Development Program for the Mining Industry*, (2007), Australian Government Department of Industry, Tourism, and Resources.

6. "Sectoral Checklist for preparation and inspection of a safety report. UNECE convention on the transboundary effects of industrial accidents & the EU Directive 96/82/EC (SEVESO II) by a consistent Checklist system", (2007), *Federal Ministry for the environment, Nature Conservation, and Nuclear Safety of Germany, Umweltbundesamt, UNECE Convention on Transboundary Effects of Industrial Accidents*.

7. *Developing an Operation, Maintenance and Surveillance Manual for Tailings and Water Management Facilities*, (2011), The Mining Association of Canada.

8. *State Construction Regulation of Ukraine B.2.4-5:2012. Tailing pits and sludge stores*, (2012), Ministry of regional development of Ukraine, Kyiv, Ukraine.

ДБН України В.2.4-5:2012. Хвостосховища та шламонакопичувачі. *Міністерство регіонального розвитку України.* – К., 2012. – 71 с.

Мета. Обґрунтування й розробка концепції Контрольного списку, застосовуваного для оцінювання та підвищення рівня безпеки хвостосховищ та водовідстійників.

Методика. Для розробки Контрольного списку хвостосховищ використаний метод контрольних питань, що дозволяє оцінити всі найважливіші аспекти їх безпечного функціонування. Цей документ включає опитувальні листи з уніфікованими варіантами відповідей та особливий порядок загального й диференційованого (за певними категоріям) оцінювання рівня безпеки хвостосховищ.

Результати. Розроблена структура та порядок застосування Контрольного списку хвостосховищ, що включає списки питань для оперативного (базового) та детального оцінювання рівня безпеки таких об'єктів, їх поточного моніторингу, а також оцінки безпеки вже експлуатованих хвостосховищ. Розроблена методика кількісного оцінювання рівня безпеки хвостосховищ з урахуванням достовірності наявної інформації, а також Каталог заходів, рекомендованих для усунення невідповідностей вимогам безпеки, виявлених при інспекції.

Наукова новизна. Уперше розроблений цілісний підхід до оцінювання рівня безпеки хвостосховищ як екологічно небезпечних об'єктів, а також детальний алгоритм проведення їх аудиту, що включає відповіді на питання Контрольного списку, їх кількісне оцінювання та припис найбільш раціональних заходів з Каталогу заходів.

Практична значимість. Контрольний список пропонується до застосування державним екологічним інспекторам, екологічним аудиторам і операторам хвостосховищ як інструмент оцінки рівня безпеки та прийняття захисних і профілактичних заходів на хвостосховищах. Каталог заходів Контрольного списку містить перелік заходів, відповідних найкращому міжнародному досвіду гірничодобувної промисловості й технологій рекультивації. Розроблений список реалізований у формі електронних таблиць з гіперпосиланнями, що зручна для практичного використання.

Ключові слова*: хвостосховища, Контрольний список, рівень безпеки, оцінювання, Каталог заходів*

Цель. Обоснование и разработка концепции Контрольного списка, применяемого для оценки и повышения уровня безопасности хвостохранилищ и водоотстойников.

Методика. Для разработки Контрольного списка хвостохранилищ использован метод контрольных вопросов, позволяющий оценить все важнейшие аспекты их безопасного функционирования. Этот документ включает в себя опросные листы с унифицированными вариантами ответов и особый порядок общего и дифференцированного (по некоторым категориям) оценивания уровня безопасности хвостохранилищ.

Результаты. Разработана структура и порядок применения Контрольного списка хвостохранилищ, включающая списки вопросов для оперативного (базового) и детального оценивания уровня безопасности таких объектов, их текущего мониторинга, а также оценки безопасности неэксплуатируемых хвостохранилищ. Разработана методика количественного оценивания уровня безопасности хвостохранилищ с учетом достоверности имеющейся информации, а также Каталог мероприятий, рекомендуемых для устранения несоответствий требованиям безопасности, обнаруженных при инспекции.

Научная новизна. Впервые разработан целостный подход к оцениванию уровня безопасности хвостохранилищ как экологически опасных объектов, а также детальный алгоритм проведения их аудита, включающий ответы на вопросы Контрольного списка, их количественное оценивание и предписание наиболее рациональных мер из Каталога мероприятий.

Практическая значимость. Контрольный список предлагается к применению государственным экологическим инспекторам, экологическим аудиторам и операторам хвостохранилищ как инструмент оценки уровня безопасности и принятия защитных и профилактических мер на хвостохранилищах. Каталог мероприятий Контрольного списка содержит перечень мероприятий, соответствующих передовому международному опыту горнодобывающей промышленности и технологий рекультивации. Разработанный список реализован в форме электронных таблиц с гиперссылками, которая удобна для практического использования.

Ключевые слова: *хвостохранилища, Контрольный список, уровень безопасности, оценивание, Каталог мероприятий*

Рекомендовано до публікації докт. геол. наук В.С. Савчуком. Дата надходження рукопису 17.03.14.