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SAFETY ASSESSMENT OF GEOLOGICAL REPOSITORIES FOR HLW AND SNF: APPLYING INTERNATIONAL EXPERIENCE TO THE ENISEISKIY PROJECT

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The article summarizes the findings of international expert groups dealing with general safety issues associated with the geological isolation of HLW and SNF. It presents main recommendations on relevant safety assessment methodology, procedures, terminology and regulatory requirements, as well as possible applications of these recommendations during the implementation of the Eniseiskiy project.

Key words: *radioactive waste, geological repository, safety assessment.*

Introduction

In 2008, Declaration on Construction of a Final Disposal Facility for Long-Lived RW (HLW and ILW of Class 1 and 2) in the Nizhnekansk Granite-Gneiss Crystalline Massive (Krasnoyarsk region, Eniseiskiy mountain range, Zheleznogorsk) was approved [1]. To date, the site selection process is completed, repository designs were presented, relevant plan discussing strategic implementation of facility's life cycle was drawn [2] and a decision in principle was made regarding the construction of an underground research laboratory (URL) at the potential site for repository construction [3]. Successful implementation of the plans mentioned above is heavily dependent on a comprehensive solution of the issues associated with safety case development. This solution is regulated by a number of regulations of various level setting up specific safety requirements.

In the mid 1980's, all basic engineering problems were deemed to be solved, namely those associated with the safe isolation of HLW and SNF from biosphere via a multibarrier system assumed to be put in place in borehole type repositories [4]. Common mine construction techniques went back a long way. Different options proposed for multibarrier principle implementation seemed to guarantee the long-term containment of radionuclides. However, it is by early 1990's that all such projects were halted due to the challenges associated with the long-term safety demonstration [5]. Literally, "eternal" hazard arising from HLW and SNF, on the one hand, and strict safety regulatory requirements, on the other, have revealed basic scientific problems associated with the reliability of relevant long-term safety assessments. To date, no such a project has been completed in the entire world which appears to be another evidence demonstrating the complexity of these problems [6]. Practical implementation of HLW geological disposal project in Russia has started later as compared to other countries, thus, enabling to apply available knowledge on the safety assessment gained under similar projects implemented abroad. This article, for instance, overviews the steps taken by the international expert community to address these problems. Moreover, the implementation of the Eniseyskiy project characterized by some specific features will provide the international community with another source of knowledge on this matter [7].

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RW and waste management

Radioactive waste generation started with the industrial development of nuclear power both for defense and peaceful purposes. Since then, RW amount has started to increase dramatically. The biggest hazard is associated with surface storage of spent nuclear fuel (SNF) and its reprocessing products — long-lived HLW and ILW. Their total volume is lower then some percent fraction from the volume of the whole RW inventory, but the high activity level, radioactive releases and required long-term isolation from human have prompted the development of geological disposal concepts. These concepts, as it was acknowledged by the international expert community, can offer a suitable technical and financial solution to this problem, minimizing relevant radiation risks for the population, eliminating the possibility of intentional theft of radioactive materials, and, above all, remove the burden for the accumulated waste from future generations [8, 9].

Common RW management technology suggesting RW storage to ensure their isolation from the population and the environment can, however, cause the risk of different accidents and radionuclide releases. Disposal being considered as an alternative to the above-mentioned storage concept suggests regulated discharge of radionuclides from the underground facility into the environment. No unique term for this type of underground facilities used to contain RW has evolved yet. International sources offer a number of options, namely repository, installation, facility, plant, which can be translated into Russian using the words literally meaning "storage facility, facility, structure, plant". A number of terms can be found in Russian literature sources that can be literally translated into English as "geological disposal facility, final isolation facility, storage facility or repository". The Russian term "mogilnik" seems more explicitly reflecting the essence of the technology. However, no equivalent term exists in the English language.

The knowledge gained in 1960-1970's showed that the underground disposal option suggests several methods to be used to enable radionuclide isolation from the environment:

- Physical isolation of RW from ground waters attained via (1) RW confinement inside metal canisters, (2) canister packaging into overpacks made of low permeable clayey materials and (3) selection of a repository area located inside water-free geological medium.
- Decreased radionuclide solubility in ground waters that can be attained via (1) their immobilization inside special insoluble matrixes, (2) selection of a site with proper geochemical setting being considered unfavorable for most radionuclides in terms of their migration.
- Retardation of convective radionuclide transport with ground waters achieved by (1) canister enclosing inside high sorption capacity materials, (2) selection of sub-soil areas with still water exchange, (3) composed of rocks with high radionuclide sorption capacity.

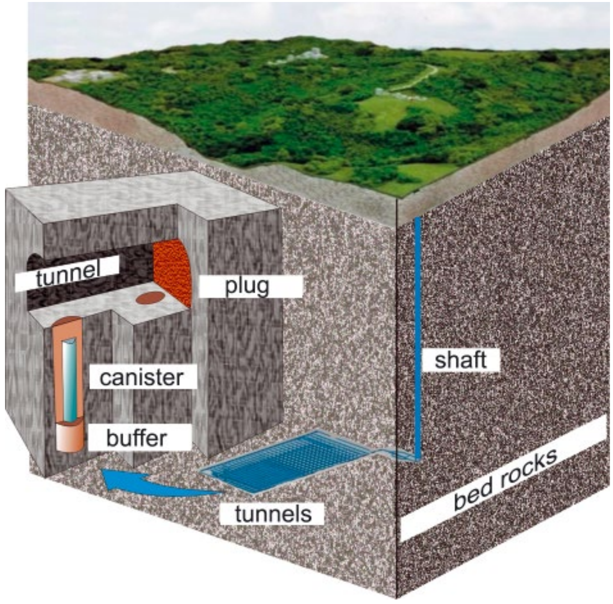

Figure 1. Layout of a multibarrier repository

The above-mentioned methods form a basis for all multibarrier repository designs developed to date (figure 1). These methods are commonly divided according to relevant functions provided: radionuclide containment inside the barrier and retardation of radionuclide leaving the barrier.

Safety concept for geological disposal facilities is based on the use of different barriers being part of the disposal system. Each barrier performs the functions assigned to it during specified time frames. Each function is ensured by relevant properties of barrier materials[1]. There are two types of barriers: artificial (engineered) and natural, associated with the geological environment selected for repository construction. According to the existing guidelines, each barrier is advised to fulfill several functions at once [10, 11].

The safety concept lying behind the multibarrier repository differs from other (simpler) engineered structures. The defense in depth provided for the biosphere and the population shall be ensured so that the safety is not unduly dependent on a single barrier or on the implementation of some function assigned to it [11].

Engineered barrier system (EBS) in typical repository structures generally involves the following elements: HLW matrix, metal canister containing the matrix, clayey buffer between the canister and the bed rocks, backfilling of transport tunnels and other underground openings, bedrocks (figure 1). However, EBS layout can vary depending on the specific

[1] English literature offers the term "safety functions". In Russian literature, however, for instance, NP-055-14, the term "protective functions" is used.

project. Alternative solutions for such programs are derived based on the way the "responsibilities" for the long-term safety between different EBS elements and geological conditions are proposed to be shared. Some unfavorable geological conditions can be, thus, offset by more advanced engineered barriers.

Safety assessment of a geological repository: challenges and evolution of approaches

Implementation of geological disposal method can be view as a cross-cutting issue:

- It was assumed that a technical solution exists enabling to ensure the safety via the use of modern technologies. The technical solution proposed in this regard was the disposal of immobilized RW in deep geological formations termed as geological disposal;
- It was assumed that the implementation of this technical solution can be ensured through relevant experimental, applied and basic scientific research;
- It was assumed that geological disposal safety can be guaranteed if relevant regulatory requirements are met which is typical for common engineering projects.

However, practical efforts have shown that safety assessment requirements result in a number of basic scientific problems. Moreover, these problems could not be solved without additional assumptions being considered quite doubtful in terms of common engineering approaches also applied in nuclear power sector. It is that these doubts are currently slowing down the completion of geological disposal projects implemented abroad. Obviously, successful implementation of the Eniseiskiy project is also highly dependent on the dispelling of these doubts.

Geological disposal safety is regulated both at international and national level. No matter how good the "protective functions" of geological media or particular engineered barriers are, an integrated safety indicator for the entire system was required to assess the safety of a multibarrier structure. Inherently absolute radionuclide isolation from the biosphere during their period of potential hazard cannot be expected. For this reason, possible radiological consequences resulting from repository construction at a particular site have been considered as repository safety indicators. Such indicators involved effective dose and radiological risk — safety indicators widely used in nuclear industry. These indicators were specified in Russian regulations covering RW disposal matters [12].

Compliance of repository designs with specified safety criteria is demonstrated by a special procedure called safety assessment (SA). This procedure enables to evaluate the quality of the entire isolation system being viewed as a combination of engineered barriers and geological media jointly preventing radionuclide release into biosphere.

As it comes to common practice, observation boreholes surrounding hazardous underground facility are used to perform measurements enabling to monitor underground spread of a contamination plume. However, in case of a geological repository comprehensive field investigations seem to be infeasible from a technical point of view due special and temporal parameters of the repository. Thus, for example, current designs of the Eniseiskiy facility suggest that the space area of its underground section shall be less than 0.2 km^2 with a vertical extent of some 75 m. Up to 200,000 m^3 of immobilized ILW and HLW of class 1 and 2 surrounded by engineered barrier system are going to be disposed of at a depth of some 0.5 km. Potential hazard period for long-lived RW amounts to some millions of years. If separate test samples of such RW or their non-radioactive analogues are placed underground, the duration of such experiments proves to be totally unacceptable. It will take some hundreds of years to see the failure of engineered barriers and the release of contaminants into the environment. Only by this time it will be possible to make necessary measurements in the observation wells. At the same time, waste disposal with no previously conducted R&Ds is considered to be unacceptable due to safety reasons.

Mathematical modeling and radionuclide release forecasting based on parameter values measured during laboratory experiments including those performed in URL, seems to be the only reasonable solution for this challenge. Based on such forecasts relevant data showing where, when, what kind and how many radionuclides are going to be released into the environment can be obtained. Based on such forecasts, relevant effective doses and risks for future generations can be derived. Calculations performed based on these forecasts should demonstrate that the established regulations on dose limits and risks (criteria) for population and the environment will be not exceeded during the whole time period while the long-lived HLW and ILW potentially remain hazardous. This approach has been established under national and international regulatory framework. Definitely, safety assessment for disposal facilities shall involve relevant simulations of the isolation system and numerical forecasts for radionuclide releases into the accessible environment. In keeping with basic safety assessment principles, forecast results should be compared with effective regulations [10, 12].

As stated above, the long-term safety of the future repository cannot be demonstrated based on experimental methods widely used in the construction of common structures. Thus, in keeping with the system approach applied during the implementation of repository projects it is the repository safety assessment that is seen as top-priority (final) goal and not its construction. Latter can be explained by drawing an analogy to a concealed uranium deposit which can not be evidenced at the

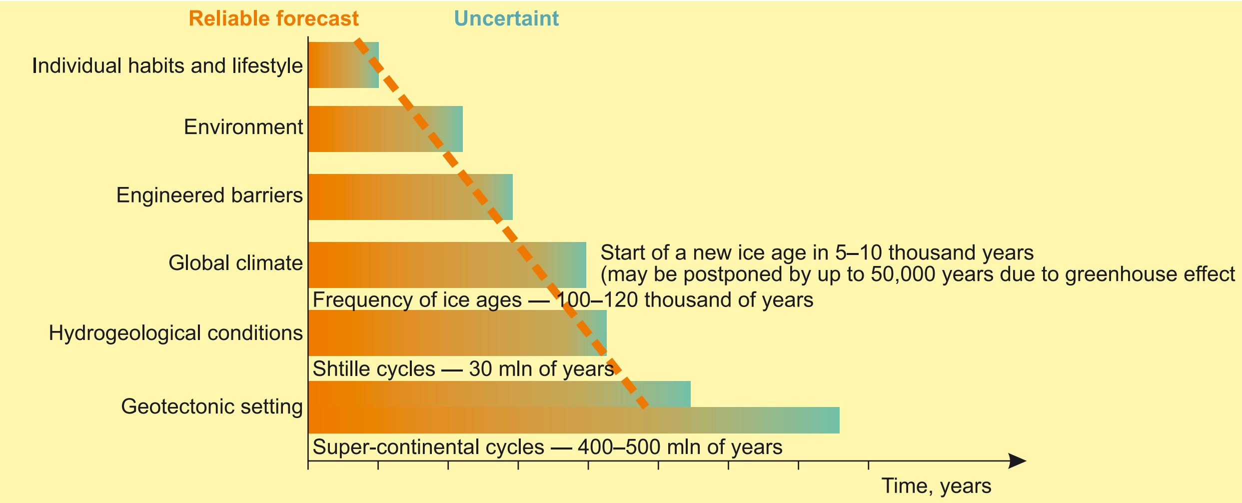

Figure 2. Time frames for reliable forecasts of the processes affecting the safety assessment of a disposal system [40]

surface via exceeded radioactive flows. A borehole for its development is drilled after the deposit was discovered. On the contrary, borehole type disposal facility shall be constructed in a way providing that the radioactivity disposed of underground is never detected in the future at levels exceeding background ones. This resulted in recommendations suggesting staged performance of safety assessment: each stage of the project implementation shall be preceded by safety demonstrations based on already performed activities. At present time, however, the design development under the Eniseiskiy project seems to be unreasonably focused on the detailed elaboration of borehole designs and facility construction. Although early safety assessments may demonstrate that the proposed design solutions require some changes to be introduced.

Forecasts and relevant modeling activities are seriously affected by the extremely long time period for which repository safety is to be demonstrated. As the time period covered by numerical modeling forecasts increases, relevant factors affecting the release of radionuclides via water flows from the repository into the accessible environment will alter. Many of such factors can be initiated due to rare natural or anthropogenic events that are considered to be hardly predictable, thus, introducing some uncertainties into modeling results. Subsequently, no confidence regarding the feasibility of the safety assessment results suggests that the task of eliminating the burden imposed on future generations due to the accumulated waste inventory viewed as the purpose of the geological disposal is not fulfilled. It turned out that due to the uncertainties associated with the long-term forecasts, future generations can still face the potential radiation impacts produced by the repository. It became clear that a firm evidence is required to show that the uncertainties in SA results produce no significant impact on the credibility of forecast calculations [5].

Non-liner properties of natural features have been revealed during the investigations of open nonequilibrium systems with geological medium being considered a case in point. By 1970's it was demonstrated that chaos propagation in deterministic systems considerably reduces the predictability of natural and anthropogenic processes [14]. Uncertainties in baseline data on EBS conditions and details regarding dynamic processes occurring therein sooner or later are prone to result in an enormous forecast uncertainty.

The time limits for reliable forecasts covering the processes that are required to be considered to evaluate radionuclide migration into biosphere, doses and risks for the population, differ by orders of magnitude (figure 2). The predictability of different processes indicating the total increase in SA uncertainties is dependent on the latter. Geotectonical processes are considered as most predictable, whereas social processes are seen as most unpredictable ones.

The challenge of managing scientific uncertainties in forecast calculations is being addressed in several ways — from upgrading relevant regulatory framework covering safety assessment aspects to in-depth investigation of processes and factors affecting radionuclide migration via ground water flow.

It seams that the first step in addressing this challenge was the regulatory classification introduced to categorize the assessments, namely: safety assessment and performance assessment[2] (PA) [16].

Analysis of the abovementioned terms — SA and PA given in different documents has shown that SA is mainly associated with the assessment of the isolation system as a whole, while PA is mostly focused on particular isolating barriers. Quantitative SA/PA estimates enable to assess the feasibility of isolation system designs at the end of each work stage and to make a decision on project abandonment, continuation or the changes required to be introduced into work flow charts. PA is seen as SA when the robustness of the entire isolation system

[2] This term has been used in [15]

is being analyzed. In this case, radiological impact on the population defines the level of such robustness. Essentially, SA can be seen as a finalizing or consolidating stage of PA, however it should not be considered as a universally acknowledged point of view [13]. Staged SA/PA enables partial minimization of uncertainties associated with the entire system evolution.

In late 1990's safety case concept aiming to demonstrate geological disposal safety was proposed by NEA OECD expert group as a tool enabling further minimization of uncertainties [17]. This procedure was called "post-closure safety case development". A set of relevant documents resulting from this procedure is called "safety case" (SC).

In some countries, SC also involves the operational safety (pre-closure) safety assessment [13, 18 — 20]. SC concept was introduced by IAEA as an international standard [11, 21]. "Safety Analysis Report" (SAR) required to be developed under Russian regulatory framework [12, 22, 23] can be viewed as SC analogue in Russia.

In keeping with IAEA standard, Safety Case provides a list of arguments and evidence demonstrating the adequate level of safety. SC is required to include assessments of doses/risks, information on the credibility of such assessments and approaches used to treat relevant uncertainties, as well as evidence and arguments supporting safety findings. The definition presented in European documents contains an important clarification: SC is a list of arguments in support of the long-term safety of the facility for the given stage of its development. These arguments include relevant decisions on the safety assessment and evidence supporting the commitment to these decisions, discuss all the issues remaining to be addressed and provide recommendations on the elimination of problems at further stages of repository development [20].

SC (or SAR) is based on three types of assessments: safety assessment, performance assessment and for some time now — safety function assessment. The latter one has been introduced in 2006 under a project implemented in Sweden [24]. Safety function or protective property[3] may be described as a role assigned to a particular part of the safety system in the safety assurance in general [25]. All these procedures basically differ from each other by safety indicators and compliance criteria being applied.

No universal system applied to categorize such indicators has been yet proposed, nor their formal definitions have been developed [25]. International projects, for example, SPIN [26] or PAMINA [27] have shown that safety indicators are used to check the compliance of the repository with the established regulations in general. Performance assessment indicators are aimed to provide an understanding and assesses the behavior of some particular elements of the system. Safety function indicators provide separate evaluation and assessment of key processes affecting the system or its elements.

Safety indicators also include such quantitative characteristics as annual effective dose or radiological risk. Non-risk indicators are additionally used in some countries, for example: radiotoxic content in the biosphere water or radiotoxic flow from geosphere. The latter ones were set due to the fact that numerical dose and risk assessment seems to have no sense in case of very long-term forecasts [28, 29]. In Russian regulations the time period for numerical calculation of safety criteria is in no way restricted.

Performance assessment indicators enable to demonstrate the performance of specific system elements or integrated performance of different barriers. It can be identified which of the system elements provide for radionuclide retardation, what are the radionuclides retarded and in what way the system can be optimized. Such indicators can correspond to entire system elements (buffer or bedrocks) or to several components (for example, canister containing waste matrix and the byproducts resulting from its interaction with water). These indicators are typically derived from radionuclide concentrations or flows inside and between particular repository system elements or based on descriptive approaches demonstrating specific system properties [30].

Safety function indicators are measured or calculated values providing a quantitively description of a particular volume assigned with the considered protective function [24]. Calculated indicator values of protective functions describe the properties of elements related to safety separately and independently [26]. For most protective function indicators, no dependencies exist regarding the fact whether the radionuclide flow is coming from the "previous" barrier or not (i.e. on the robustness of the "previous" barrier or component). For example, for buffer protective function, the indicators that can be considered are as follows: hydraulic conductivity and swelling pressure specifying the capability of buffer to limit convective transfer of radionuclides with water flow. Such indicator as buffer density determines its capability to attenuate rock displacements along fractures or to reduce microbiological activity.

Quantitative assessment of safety, performance and safety functions requires that relevant indicators are expressed in measurable or calculatable values and relevant criteria are set, which seems not always possible in case of performance assessment and safety function assessment.

Safety criteria presented in international and Russian regulations are set as numerical values for allowable annual effective doses and individual radiological risks. Safety of the system is being assessed for the time period after HLW and SNF is loaded into underground facility and its transfer

[3] Relevant comments regarding the use of term "protective property" have been presented above

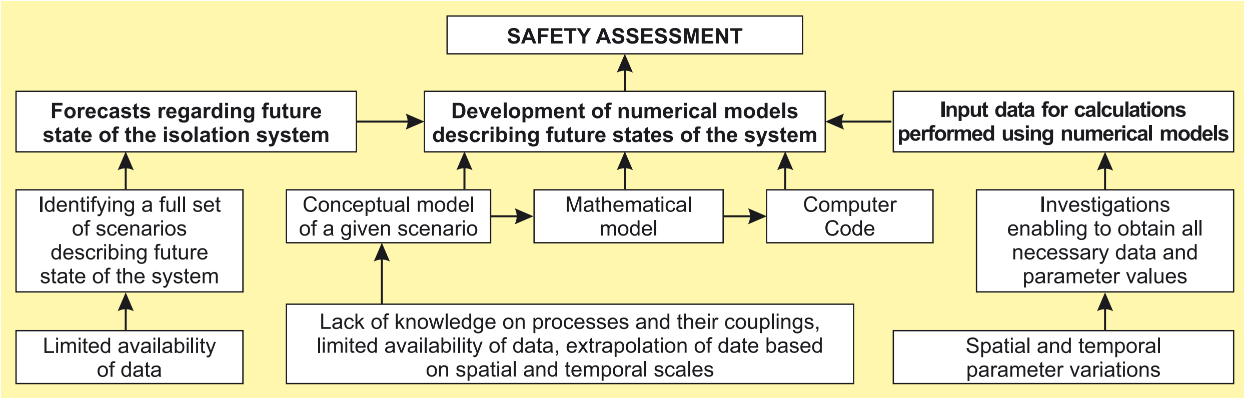

Figure 3. Sources of uncertainties in the safety assessment of RW repositories (composed based on [34])

into repository mode for the required isolation time, i.e. starting from the closure until actual hazard associated with the waste disposed of therein ceases to exist. Dose and risk calculations are based on the forecasts on radionuclide release into surface waters. Radionuclides enter the food chain directly with water and other food chains, such as water — plants — human or water — animal — human and others. The total amount of radionuclides that entered the human body determines the individual dose from which the risk of cancer diseases can be derived. Numerical values of safety criteria are set up by national regulatory authorities.

To observe the dose limit established for public, radioactive waste repositories are recommended to be designed in a way that the calculated dose or risk value for the public that may be exposed in the future due to possible natural events impacting the geological disposal safety is lower than 1/3 of the dose limit or 0.3 μSv/year. The limit associated with the risk of death from cancer should account for some 10^{-5} per year [11, 12].

Annual effective dose limit for public considering the entire lifetime of 70 years established in Russian regulations accounts for 70 μSv, i.e. 1 μSv/year [31]. The part of radioactivity associated with RW after waste disposal shall not exceed 0.01 μSv [32], i.e. definitely lower than the background radioactivity level coming from natural sources (rocks, solar radiation and etc.).

Safety criteria derived from "non-risk" indicators can be exemplified as follows:

- Concentrations of radiotoxic components in biosphere water shall not exceed the limits established for drinking water;
- Flow of radiotoxic components from geosphere (Sv per year) to the accessible environment shall not exceed the flow of natural radionuclides present in ground waters in the repository area.

Management of uncertainties

Dose and risk forecasts for future generations are always associated with uncertainties — this realization became a challenge for the scientific community, thus, providing an indication for the contents of R&D programs for many years ahead. It became clear that convincing evidence shall be gained to demonstrate that the uncertainties present in safety assessment produce no significant impact on the credibility of forecasts [5].

In a most general way, uncertainty may be considered as a property describing something that has not been clearly identified, for example, "indefinite position". In fact, in disguise the term "uncertainty" involves some subject involved in decision-making [33].

It was in 1980's that the challenge of uncertainty management during safety and performance assessment of SNF and RW repositories was first acknowledged [34]. In 1991, NEA OECD paper was published stating that safety assessment results were always associated with uncertainties [35]. To date, uncertainty management is specified as an important procedure being part of forecast modeling process in general and under the decision making on the assessment of processes taking place in disposal system in particular. Uncertainty Management section has been included to all guidelines on the safety assessment of SNF and HLW repositories, inducing the Russian ones [23].

As shown in [34], sources of uncertainties are multiple and are being introduced to the computational model via 3 main ways: long-term forecast on the disposal system, the model development process and the data used. Each of the ways mentioned above, in turn, contains a variety of individual procedures, circumstances and situations contributing to particular uncertainties (figure 3).

So far as different kinds of uncertainties are intrinsic for the safety case development process, the goal of current research in the area of RW disposal is to reduce the remaining uncertainties, to describe them quantitively, as well as to develop relevant management strategy under regulatory decision-making process [13]. These issues are, for example, being addressed under the PAMINA project (www.ip-pamina.eu).

The system for uncertainty classification given in International guides is generally based on their role in the safety case:

- Scenario uncertainties are associated with hardly predictable changes that can reveal themselves with time under physical processes taking place inside EBS and the bedrocks.
- Model uncertainties are associated with incomplete understanding of system behavior as a whole or some processes in particular, the use of simplified representations as part of assessment models and computer codes.
- Parameter uncertainties and data uncertainties are associated with incomplete knowledge, unavailability or failure to provide accurate measurement [20, 25].

All three types of uncertainties presented above are interrelated and may be treated in different ways depending on their nature.

Uncertainty classification depending on their nature seems to be more adequate from scientific perspective as it indicates relevant ways for uncertainty management [36, 37].

Uncertainties of type 1 are associated with the chosen value of some parameter and may result from a lack of knowledge on particular location or existing relationships between parameters in the model. Theoretically, they may be completely eliminated by detailed investigations and repeated measurements carried out to reduce measurement uncertainties and to increase the accuracy of measurements. Uncertainties of type 2 are associated with random phenomena. These include natural (natural disasters) or anthropogenic (equipment failure) phenomena, as well as human activities (man caused accidents) introducing a random factor into measurements and forecasts. These can be minimized by increasing the sample volume, although, they can not be eliminated completely. Uncertainties of type 3 are associated with events that can occur in a time period sufficiently exceeding the mankind history considering the situations when a decision has to be made straight away not waiting until accurate experimental result becomes available. No statistics can be possibly gained regarding the adequacy assessment for the model chosen to perform relevant forecasts (true/false). In such cases researcher should consider its conclusions and decisions as credible based on his own conviction regarding the adequacy of proper reasoning.

Unfortunately, uncertainties of type 3 are quite usual for long-term safety assessment. Management of these uncertainties is considered to be a most significant challenge. Different methods can be applied: sensitivity analysis, mathematical assessment of expert judgments, qualitative expert judgements.

In general, it is considered to be impossible to make long-term forecasts for rapidly changing factors. In these cases, so called “stylized” (simplified but conservative) assumptions are used [25]. For example, this is the case of such procedures as absorbed dose calculations associated with rapidly changing environmental factors and dietary habits of the population [38]. To reduce the uncertainties associated with human activities in the far future, current human activities (life style) and existing safety regulations should be used to describe any future activities. The stylized approach neutralizes the impact of this kind of uncertainties but does not eliminate them in principle.

Occurrence of some uncertainties can be eliminated if their source is eliminated based on regulatory provisions. For example, a relatively short time period for numerical dose and risk calculations can be set, as well as non-risk indicators for more long-term forecasts requiring to consider a smaller number of factors subject to alterations [25]. Scenario approach is being used for processes the long-term forecast of which is being associated with multiple altering factors [25]. This approach was proposed to be used under two types of safety assessments: deterministic and probabilistic.

Deterministic approach suggests that forecast calculations are performed for a set of multiple scenarios presenting probable evolution of the repository. Evolution scenario is seen “as a possible sequence of interrelated natural or anthropogenic events, phenomena and factors, as well as physical and chemical processes determining the evolution of RW disposal system, radionuclide migration to the environment and human exposure” [12]. Two approaches enabling to identify features[4], events and processes (FEPs) are being used today [25]. Bottom-up approach[5] suggests that external events or conditions (climate changes, initial canister defects and etc.) capable of initiating some changes in the disposal system or to impact its performance should be considered in the first place. Another approach to scenario development (top-down approach) suggests that first the adequace of protective barriers should be evaluated in terms of providing relevant protective functions and radionuclide containment during the required time period.

FEPs data bases have been developed addressing either all repository types, for example, European base [39], or covering some particular geological formations (for example, crystalline rocks for Swedish and Finnish disposal projects). The identified FEPs are combined to represent specific possible scenarios for disposal system evolution. Calculations covering sufficiently exhaustive scenario sets should provide an adequate framework for a credible forecast.

It should be noted that available FEPs bases developed under international projects cannot be directly applied to the Eniseiskiy project which is associated with particular features of the disposed waste, original EBS layout and geological setting [40].

To assess radiological consequences, probabilistic assessment methodology can be used to

[4] In Russian this word can be also translated either as factors (as given in NP-055-14) or characteristics

[5] These terms were taken from the proposed methodology for comprehensive system analysis

complement the traditional deterministic approach. Probabilistic safety assessment is based on a probabilistic approach to identifying scenarios, generalizing parameter values and applying mathematical tools to derive quantitative risk and dose estimates [41]. This methodology involves three consecutive steps. At the first step, hazardous events causing prime harm and their frequency is evaluated. The second step enables to evaluate the impact of these events on radionuclide release providing estimates for the frequency and the amount of such releases into the environment. The third step is focused on the consequences of such releases – relevant doses and risks for the population are estimated.

Each of the abovementioned approaches (deterministic and probabilistic) has its pros and cons. It is important to note that none of them is able to provide an explicit forecast representing future system behavior, but to estimate possible radionuclide release impacts on biosphere and population [42].

Problem of trust

Safety case development also involves the so call "problem of trust" associated with the credibility of the calculated safety indicator values being derived based on numerical repository post-closure modeling covering a very long-term period [13]. It is assumed that waste disposal can start only after all the stakeholders (operator, regulator, local authorities and the public) gain adequate level of confidence suggesting that the repository is going to be built according to relevant designs developed. However, in practice, it turned out that no clear mechanisms and criteria exist suggesting that the problem of trust had been solved [43]. Due to remaining uncertainties, no clear answer to the question on the type and the number of investigations that are required to be performed to gain an adequate level of confidence in the assessments performed and to start actual disposal operations exists. This area of research has recently become a priority one.

The problem of trust could also explain particular attention devoted lately to the quality management of the technical aspects associated with repository projects. As far as radionuclide releases due to possible mistakes and miscalculations of current experts may be manifested in the biosphere not earlier then after some hundreds and even thousands of years, "effect of so-called deferred punishment" for poor-quality work execution has been revealed. This places particular demands on experts performing relevant activities and draws special attention of regulatory authorities and public.

According to the experts, the problem of trust can be solved easier if the information on geological disposal projects, including the Eniseiskiy project, becomes available to a greatest possible extent not only to the experts involved in such projects, but also to outside observers – scientific community and general public.

Conclusions

An important statement can be made based on the general defense-in-depth concept ensuring the safety of the population and the environment: not a single barrier function or barrier in general may not be considered adequate unless a safety assessment covering the entire multibarrier disposal system is completed. To date, R&Ds performed under the Eniseiskiy project are not considered sufficient enough to provide a final statement on the safety and performance of the entire system, as well as on the protective functions of its barriers.

Multibarrier repository structure, considering the engineering solutions proposed under the current designs, requires the performance of regular R&Ds enabling to ensure the reliability level attainable with currently available knowledge and technologies.

A specific goal has been assigned to the academic community as well – to identify the highest possible level for the performance assessment carried out under Russian geological disposal project. This level will reveal the possible knowledge and safety demonstration level the design organizations and the operator should be committed to, as well as the impossible one that the regulatory authorities and public environmental organizations have no right to claim for.

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