International Peer Review of the Deep Well Injection Practice for Liquid Radioactive Waste in the Russian Federation

Final Report of the IAEA International Review Team July 2013

IAEA
International Atomic Energy Agency

INTERNATIONAL PEER REVIEW OF THE DEEP WELL INJECTION PRACTICE FOR LIQUID RADIOACTIVE WASTE IN THE RUSSIAN FEDERATION

The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world''.

INTERNATIONAL PEER REVIEW OF THE DEEP WELL INJECTION PRACTICE FOR LIQUID RADIOACTIVE WASTE IN THE RUSSIAN FEDERATION

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2020

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FOR LIQUID RADIOACTIVE WASTE IN THE RUSSIAN FEDERATION
IAEA, VIENNA, 2020
IAEA/WAS/RUS

Printed by the IAEA in Austria
September 2020

FOREWORD

The IAEA safety standards reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from harmful effects of ionizing radiation. The process of developing, reviewing and establishing the IAEA standards involves the IAEA and all Member States, as well as some international organizations. The IAEA standards are a key element of the global safety regime. The IAEA's safety services encompass design, siting and engineering safety, operational safety, radiation safety, safe transport of radioactive material and safe management of radioactive waste, as well as governmental organization, regulatory matters and safety culture in organizations. These safety services assist Member States in the application of the standards and enable valuable experience and insights to be shared.

Upon request from the Russian Federation, the IAEA organized an international peer review of the deep well injection practice for liquid radiative waste. The objective of the review was to provide an independent international evaluation, based on the requirements set out in the IAEA safety standards, of the safety of deep well injection practices for liquid radioactive waste management in the Russian Federation.

This publication presents the consensus view of the international group of experts convened by the IAEA to perform the review. The IAEA officer responsible for this peer review was G. Bruno of the Division of Radiation, Transport and Waste Safety.

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1. INTRODUCTION

The Russian Federation nuclear programme produces liquid radioactive waste and effluents. The major fraction of liquid radioactive waste accumulated at Russian nuclear industry enterprises is the result of the former defence nuclear activity.

In the former Soviet Union, the severe impacts from the discharge of radioactive waste to the surface waters, and the waste tank explosion at Mayak in 1957, prompted the specialists in the atomic industry and the Academy of Sciences to seek other options for waste management.

Work started in the latter half of the 1950's to explore the possibilities of geological disposal by injection of the liquid radioactive waste. After extensive testing of the concept in the laboratory and in the field, and numerous calculations of the likely consequences of deep well injection of liquid radioactive waste, deep disposal into geologic formations was initiated in the Soviet Union in the early 1960's.

This practice is implemented at three different sites of the Russian Federation territory, The Siberian Chemical Combine (SCC), State Scientific Centre - Research Institute of Atomic Reactors (RIAR) and the Mining and Chemical Combine (MCC).

Both low and intermediate level radioactive waste has been disposed of in the different sites. Earlier on at SCC and MCC high-level liquid radioactive waste was also isolated for experimental purposes from the environment through the same technology, but this practice was terminated.

Due to the shutdown of the production reactors and the reduced rate of fuel reprocessing, the rate of waste generation has declined considerably in recent years.

Though all three existing sites are still in use, the Russian authorities are not planning to continue to exploit them in the long term, and seek to store and dispose of the radioactive waste in solid form.

1.1 OBJECTIVE AND SCOPE

In 2010, the Russian Federation requested the IAEA to organize an international peer review on the deep well injection practice for the liquid radioactive waste.

The objective of the review was to provide an independent international evaluation, based on the requirements set out in the IAEA safety standards, of the safety of deep well injection practices for the liquid radioactive waste management in the Russian Federation.

The peer review addressed the disposal activities related to liquid radioactive waste injection in the Russian Federation and gave a particular attention to the safety basis and justification for the borehole injection disposal practice including assessment of the long-term impacts on the human health and environment.

The Terms of Reference are given in Appendix 1.

1.2 CONDUCT OF THE REVIEW

The review was conducted by a team of five senior international experts in different topics relevant to the scope of the peer review. They were selected from IAEA Member States and are familiar with IAEA safety standards and have extensive experience in the geological disposal of radioactive waste. The members of the international peer review team (The PRT) were selected by the IAEA Secretariat and accepted by the Russian Federation (ROSATOM).

The PRT assembled by the IAEA comprised Christophe Serres (France) PRT chairman, Jussi Heinonen (Finland), Wolfgang Goldammer (Germany), Wolfgang Kickmaier (Switzerland) and Abraham Van Luik (USA).

The PRT was supported by two Scientific Secretaries from the IAEA, Gerard Bruno from the Waste and Environmental Safety Section of the Department of Nuclear Safety and Security and Peter Ormai from the Waste Technology Section of the Department of Nuclear Energy.

The overall peer review process consisted of three phases:

(a) Preparation and initiation - A preparatory meeting between the IAEA and the Russian Federation was held in July 2012 to develop the Terms of Reference, including the scope of service, the work plan and the appropriate reference documentation supporting the peer review;

(b) Initial information - This phase included the self-assessment exercise according to the questionnaire and the transmission of its result and any other existing information by the Russian Federation and its subsequent distribution by the IAEA to the PRT members for preliminary evaluation;

(c) Review meetings – The purpose of the meetings was to enable the Russian Federation to give comprehensive presentations of its liquid radioactive waste management practice with the use of deep well injection, and gave the opportunity to the team members to hold technical discussions on specific issues (e.g. response to issues identified by the team), and discussions with the Russian Federation experts.

The peer review was organized in two stages:

- A pre-mission in December 2012 during which the experts performed a preliminary review of the documentation provided by the Russian Federation regarding the safety of the liquid injection practice. This pre-mission allowed in particular identifying any additional information and documentation to be provided by the Russian Federation prior to the final peer review mission;

- The final peer review mission from 28 June to 5 July 2013 with the objective to perform the evaluation of safety of the liquid injection practice in the Russian Federation, on the basis of the complementary information and documentation provided. A site visit at the Research Institute of Atomic Reactors in Dimitrovgrad was organized during the final mission.

The final peer review mission took place in ROSATOM and IBRAE's premises in Moscow. The peer review report presents the consensus view of the international group of experts (the PRT) convened by the IAEA for carrying out the review.

The peer review report has been reviewed by the Russian Federation counterparts, for factual accuracy, in order to ensure the conclusions of the review have a factually correct basis. All meeting records and correspondence involving the Russian Federation counterpart and the IAEA regarding the review process have been retained in order to provide a record of the independence of the review process.

1.3 BASIS FOR THE REVIEW

The reviewers based their comments and evaluation on the responses to a self-assessment questionnaire provided by the PRT on 4 reports (A, B, C and D) and an accompanying note in English provided to the experts prior to the review mission, on the responses to the questions developed by the experts from the reports and on presentations and discussions during the review meeting in Moscow. References of the documents submitted for the purpose of the peer review are given in Appendix 3. The peer review was carried out with reference to the relevant IAEA Safety Standards. The IAEA safety standards reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from harmful effects of ionizing radiation.

In particular the peer review aimed at evaluating if the practice of injection of liquid radioactive waste in the Russian Federation is in line with the Safety Requirements on Disposal of Radioactive Waste, SSR-5 [1]. This Safety Requirements publication establishes safety requirements relating to the disposal of radioactive waste of all types. It sets out the safety objective and criteria for the protection of people and the environment against radiation risks arising from disposal facilities for radioactive waste in operation and after closure.

Other relevant safety requirements and safety guides were also used for the purpose of the peer review (e.g. SF-1 [2], SSG-14 [3], SSG-23 [4]…) as well as other specific documents such as the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [5] and ICRP publications [6].

The report from the experts has been developed using the structure of the safety requirements with the following main sections:

- Introduction;
- Existing disposal facilities;
- Planning for the disposal of radioactive waste;
- Development, operation and closure of a disposal facility;
- Assurance of safety;
- Conclusions.

During the mission in the Russian Federation, a visit of the RIAR site in Dimitrovgrad was organized. This visit, of high interest, allowed the experts to have a more realistic perception of the practice of liquid injection and to discuss with experts on the site. No specific observation can be made on the basis of the visit on the safety of the practice of injection of liquid radioactive waste for the NIAAR site in particular neither for the practice of injection of radioactive waste in the Russian Federation.

2. EXISTING DISPOSAL FACILITIES

Russian Federation's position

Article 12 of The Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [5] states that "*Each Contracting Party shall in due course take the appropriate steps to review:*

(i) the safety of any radioactive waste management facility existing at the time the Convention enters into force for that Contracting Party and to ensure that, if necessary, all reasonably practicable improvements are made to upgrade the safety of such a facility;
(ii) the results of past practices in order to determine whether any intervention is needed for reasons of radiation protection bearing in mind that the reduction in detriment resulting from the reduction in dose should be sufficient to justify the harm and the costs, including the social costs, of the intervention."

As indicated in [1], "*Some disposal facilities that were developed and constructed and entered into operation before these requirements were established may not meet all the requirements. These facilities may be operational or non-operational […]. These would be considered 'existing situations' in which the government would have to take responsibility for the facilities*".

More precisely, requirement 26 of [1] on existing disposal facilities indicates that "*The safety of existing disposal facilities shall be assessed periodically until termination of the license. During this period, the safety shall also be assessed when a safety significant modification is planned or in the event of changes with regard to the conditions of the authorization. In the event that any requirements set down in this Safety Requirements publication are not met, measures shall be put in place to upgrade the safety of the facility, economic and social factors being taken into account*."

In addition, "*Disposal facilities that were not constructed to present safety standards may not meet all the safety requirements established in this Safety Requirements publication. In assessing the safety of such facilities, there may be indications that safety criteria will not be met. In such circumstances, reasonably practicable measures have to be taken to upgrade the safety of the disposal facility. Possible options may include the removal of some or all of the waste from the facility, making engineering improvements, or putting in place or enhancing institutional controls. Evaluation of these options has to include broader technical, social and political issues*."

The PRT notes that the deep disposal facilities (DDFs) related to the practice of injection of liquid radioactive waste in the Russian Federation are considered existing facilities in the sense of requirement 26 of [1]. As a matter of fact, in the 1950's, investigations have been initiated on the disposal of liquid radioactive waste by injection in geological formations and in 1958 the Government of the USSR issued the Resolution on the conduction of geological prospecting works and other investigations associated with deep disposal of liquid radioactive waste at the Siberian Chemical Combine (SCC) in the Tomsk Region, the Mining and Chemical Combine (MCC) in the Krasnoyarsk Krai, PA “Mayak” in the Chelyabinsk region and RIAR in the Ulyanovsk region.

Investigations were carried out simultaneously in several areas and at several sites. One of the priority tasks was to ensure radiation safety of disposal. The following studies were performed to address this issue: assessment of the potential impact of liquid radioactive waste disposal on the environment, predictive assessment of disposal consequences and development of hygienic conditions of soil and subsoil use for disposal purposes. On the basis of this exploratory work, the SCC, MCC and RIAR sites were selected for disposal of liquid radioactive waste by injection. The sites of PA «Mayak» were judged to be unsuitable for liquid radioactive waste (LRW) disposal.

The different stages of liquid radioactive waste deep disposal project in the 3 selected sites are given in the following table 1:

TABLE 1. THE DIFFERENT STAGES OF LIQUID RADIOACTIVE WASTE DEEP DISPOSAL PROJECT

Stage, works	**Time intervals**			
	SCC	**MCC**	**RIAR**	PA “Mayak”
Resolution of the Government of the USSR on the start of research	1958			
Preliminary research and design activities	1958-1965	1958-1963	1962-1970	1961 - 1970
Trial Operation	1963-1974	-	-	-
Commissioning	1967 (site 18) 1975 (site 18a)	1967(I horizon) 1969(II horizon)	1966(III zone) 1973 (IV zone)	-

Since then the practice of injection of liquid is being implemented in the Russian Federation in the 3 sites.

According to the documentation provided by the Russian counterpart, the Federal Law of 1 December 2007 on the State Atomic Energy Corporation “Rosatom” states that the State Corporation “Rosatom” implements authority and functions of the management body in the field of radioactive waste management (Article 7). As such Rosatom is responsible for the practice of injection of liquid radioactive waste in the Russian Federation. In 2011 the Federal Law on the Management of Radioactive Waste was enacted. In particular, the law, under article 30, states that the disposal of liquid radioactive waste is limited to the existing facilities under operation and construction of new facilities is not allowed. The law also indicates that the ownership of liquid radioactive waste disposal shall be transferred to the National Operator before July 2013. As the license validity period for the existing facilities is limited to the period up to July 2013 inclusively, and the licenses shall be re-issued to the National Operator upon their expiry. On July 2, 2013 the Federal Law № 188-FZ "On amending to the Federal Law "On the State Atomic Energy Corporation ROSATOM" and some legislative acts of the Russian Federation" has come into force. According to this law the validity of current licenses is prolonged for a year. In other words, for liquid radioactive waste disposal facilities - it's up to July 2014. According to Document A and in relation to the law of 2011 and the issuance of licenses to the National Operator, "new requirements set by the radioactive waste management law shall be implemented in the regulatory documents of various levels currently under development (decrees of the Russian Federation Government, federal codes and standards, etc.). Detailed study of the radiation monitoring and closure issues in application to the operating facilities will be required, and highest priority should be assigned to long-term safety and safety assurance at closure and post-closure stages. The consequence of new requirements would be identification of the period of potential hazard of disposed waste and the obvious necessity to maintain safety within this period. Re-consideration of 1000-year period initially regarded as sufficient for long-term safety is inevitable."

PRT observation

Because injection started in the early 1950's, it is understandable that requirements on the preparation, approval and use of the safety case and safety assessment are not fully met. This situation makes difficult the compliance with safety requirements as developed in the IAEA SSR-5.

A set of Russian documentations issued on the request of different national authorities appears to exist. But from the documentation provided for the peer review and the discussions during the peer review mission it appears that there is no integrated long-term safety evaluation of the practice of injection of liquid radioactive waste. A number of experimental works and quantitative evaluations have been developed but without sufficient perspective on how this collection of arguments can contribute to build confidence in the safety of the disposal and communicate the overall understanding of the long-term evolution of the overall system of the liquid radioactive waste injected in the geological formations. The approach used to evaluate the safety of the DDFs is mainly related to the identification of the total and annual volume and activity of discharged waste, the monitoring of the consequences of the injection practice and the comparison with forecast calculations of the spreading of the radioactive plume. The practice even at the beginning was to start investigations, in conjunction with development of the practice then to ensure through monitoring that the consequences of the injection practice are limited and acceptable. The PRT notes that this practice continues basing safety demonstration on updated forecast calculations and monitoring aiming at proving that because today disposal is under control it will remain safe in the far future. This general approach needs to be re-examined along the general principles of the Safety Requirements on Disposal of Radioactive Waste [1], requesting in particular the development of an integrated safety case.

RECOMMENDATION

The PRT recommends presenting in an **integrated manner in the safety case**:

- the main characteristics of the disposal facility components and the processes on which the safety functions rely,
- The understanding of the evolution of the disposal system: characterization of the processes affecting the waste and the geological medium
- a selection of the issues to be further investigated so as to enhance confidence in safety demonstration up to a level considered as satisfactory,

- a description of the researches, tests and modelling to be implemented on these issues, with due consideration in providing **results that are representative of the current and foreseen disposal facility conditions,**
- A **qualitative and quantitative assessment** of the safety of the system (based on different kinds of indicators),
- An identification and management of the **uncertainties**
- An identification of the issues deserving **further consideration** (update of investigation program, modification of the design, etc…)

Most of these elements are discussed and presented in more detail in the development here after.

3. PLANNING FOR THE DISPOSAL OF RADIOACTIVE WASTE

3.1 SAFETY STRATEGY

The safety strategy guides any particular step of development of the project through the definition of the basic principles upon which the disposal facility is developed to reach a level of safety commensurate with the potential hazard and its duration procured by the radioactive waste. It should in particular address how **defense in depth** is developed according to the characteristics of the waste to be disposed, which **safety functions** will be assigned to the various components of the disposal facility and what **program of investigation** is needed to confirm that these functions are effective, including in particular an approach to **manage uncertainties**. The elements of demonstration over which the program of investigation backs up must be described in the safety strategy. The features and processes relevant to perform the **safety assessment** and which form in particular a hierarchy of the issues to be treated should be provided and justified.

The background and the context of [1] (paragraphs 1.6.and 1.7) specifies that "*The preferred strategy for the management of all radioactive waste is to contain it (i.e. to confine the radionuclides to within the waste matrix, the packaging and the disposal facility) and to isolate it from the accessible biosphere [...]*" and that "*Radioactive wastes may arise initially in various gaseous, liquid and solid forms. In waste management activities, the waste is generally processed to produce stable and solid forms, and reduced in volume and immobilized, as far as practicable, to facilitate their storage, transport and disposal [...]*". According to these management principles, most international practices for disposal of radioactive waste management rely mainly on the management of all radioactive waste by confining the radionuclides to within **a waste matrix and the packaging** in the disposal facility and to isolate it from the accessible biosphere.

Russian Federation's position

The overall strategy implemented by the Russian Federation is to directly inject liquid radioactive waste inside the specially selected geological formation. The geological formation is selected so that to offer sufficient pore space and transfer capabilities to make it possible the movement of radioactive liquid from the basement of the injection borehole and to hold the radionuclides within the volume of the reservoir bed defined by the so-called allotment area. In particular, safety is ought to be ensured by the capability of the reservoir bed to limit the dispersion of the radioactive plume within the allotment area, in particular by considering the relying on the partial solidification of radionuclides due to sorption processes and by its isolation from water resources located close to the reservoir bed. This requires gaining confidence in the movement of liquid radioactive waste inside the reservoir, in its homogeneous migration within the entire pore space and in the fact that the activity will decrease within the limits of the reservoir to such a level that any leakage of radioactivity into the accessible aquifers and biosphere would not lead to unacceptable radiological impact on the human and the environment. Such confidence relies on data (radionuclides concentrations, various parameters related to the behavior of the undergrounds when liquid radioactive waste is injected) measured in observation wells around the injection location and on forecast calculations of the plume spreading. The combined analysis of data and models aims at demonstrating that the containment of LRW is ensured as expected and the conclusion of such analysis is that there is no reason for considering that the current containment could be ruled out in the far future.

Russian Federation has indicated that the Russian policy for future LRW management is solidification of waste prior to disposal. It is the aim of requirements stated in Federal law of 11 of July 2011 (No 190-FZ).

PRT observation

The key safety aspects describing the containment function of a disposal facility as presented in the background of [1] (the waste matrix, the packaging and the disposal facility that confine the radioactive waste) are not considered in the injection practice which is more similar with a discharge practice. The reservoir bed plays the role of the first barrier of what the Russian Federation considers being a multi-barrier system composed of low permeable layers. But contrary to the usual concept of multi-barrier system developed internationally, this first barrier does not prevent, to a defined period of time, the radioactive waste to leak into the geosphere since the liquid waste are already placed directly into the geosphere. By conception, the slow release of radionuclides from a first containment barrier that would be manufactured, tested and finally commissioned in such a way that its properties are duly specified (upon the characteristics of the waste (half-live, chemistry)) is not considered.

Contrary to existing or planned surface or geological disposals, the PRT notes that the concept does not define any first containment barrier ensured by the solidified waste form and the waste package which would first contribute to the decrease of radioactivity inside the waste package for the LLW and immobilization of the radioactive waste close to the location where they are disposed of before spreading into the geosphere.The PRT is of the opinion that injection of liquid RW directly into the geosphere gives rise to a conflict with the specific aims of a disposal that is to contain and isolate the waste and to inhibit, reduce and delay the migration of radionuclides at any time from the waste to the accessible biosphere.

RECOMMENDATION

The Russian Federation should continue with the development of waste solidification methods for LRW and engage with the development of disposal concept that follows the approach described in the Safety Requirements for Disposal of Radioactive Waste [1].

3.2 MULTIPLE SAFETY FUNCTIONS; CONCEPT FOR CONTAINMENT AND ISOLATION

Russian Federation's position

The Russian Federation has stated that LRW disposal facilities shall provide a number of safety functions. Multi-barrier protection of the system is provided by the justified and specially selected properties of the geological environment: the rock matrix (retention of radionuclides by sorption), the reservoir bed (low groundwater flow rate, capacity properties, and mineralogical composition), the aquitards (low permeability factors, mineralogical composition) and vertically protective buffer layers.

The liquid radioactive waste is directly injected in the rock formations with no solidification prior to disposal. The Russian position is that partial solidification is taking place after injection by sorption on the mineralogical phases. There are no engineering barriers represented by underground structures aimed at prevention of radionuclides spreading, however the operational modes for injection aimed at maintaining the safety-important geological properties of the environment and assuring the required level of safety.

The Russian Federation understanding is that each safety barrier functions independently, therefore failure of one of the barriers does not jeopardize the other primary safety functions (retardation, retention and isolation). If, for example, the flow rate is increased, then the retardation and retention will be provided by the sorption barrier and sorption retardation in the reservoir bed.

According to the information given to the PRT, the safety functions are provided by:

- The general geology of the region;
- The properties of the system elements;
- The design and materials of the wells;
- The processes of waste interaction with rocks (sorption);
- The injecting operating procedures.

The Russian Federation has stated that for the LRW disposal "containment" is described as prevention and limitation of release of radionuclides in quantities above the preset values (concentration limit set for drinking water) within a certain period of time (period of potential hazard for a certain waste component) beyond the boundary of the allotment area.

This post-closure containment safety function is provided by low flow rate of underground waters in the reservoir bed, as well as by sorption of radionuclides in clay minerals of the reservoir bed and aquitards, strengthened by special selection of chemical composition of injected waste. The vertical containment is provided by the physical properties of the geological environment - confining clay layer (or several layers), presence of buffer aquifer, low pressure difference, and quality of materials and structures providing tightness of wellbores, annular and tube space of wells. Major part of activity is assumed to decay inside the containment area (allotment area).

Several conditions are considered to allow the isolation function to be effective. In order to minimize the likelihood of human intrusion, isolation of waste from the accessible biosphere is provided by the depth of the reservoir bed and the absence of economic interest. In particular, the reservoir bed is located at a depth deeper than required for drilling wells for water purpose. The waters of upper layers are considered to be more attractive than that of lower aquifers. An important additional aspect of the isolation function is linked to the institutional control to be put in place after closure of the DDF. According to Russian Federation Federal law, institutional control should last all over the period of potential hazard created by the waste, which period is being considered to be up to 10^6 years.

PRT observation

As already observed in section 3.1, the multiple safety function principle is not derived as generally done by the definition of a multi-barriers/multi-components system that allows to a certain level of complementarity between components for assuring the function of containment of waste. A consequence of the concept adopted by Russian Federation is to be less robust as those based on multi-barriers systems in case of unexpected events of degradation of the disposal environmental conditions (ingress of water, less sorption capabilities…).

The safety of the already existing deep injection facilities should be assessed through comprehensive post-closure safety assessment to demonstrate the level of possible robustness of a system relying solely on safety functions provided by the geological host formations. The PRT appreciates the site characterization done during the facilities development and long monitoring activity which can be used to support the assumptions made for hydrological conditions and radionuclide migration. However, the documentation and the discussions during the mission did not provide comprehensive demonstration supported by experimental and monitoring results, that the proposed conceptual models describing the key safety processes actually take place in reservoir bed. In particular, the PRT notes that the main safety function regarding containment of radionuclides inside the reservoir bed is sorption. The PRT considers that this geochemical process is, as a consequence, of very high importance and would deserve a specific attention in the safety demonstration. Regarding the isolation function, according to [1] isolation shall be provided for several hundreds of years for low level radioactive waste (LLW) and several thousands of years for intermediate level waste (ILW). The PRT notes that active surveillance for avoiding human intrusion is a required condition for ensuring safety after closure and efficiency of the isolation function. The presence of long-lived radionuclides in the inventory already injected, as for the containment function, is an issue for the isolation function and a matter of concern for the definition of the duration of active measures to avoid any intrusion or water consumption. These observations rise uncertainties concerning safety demonstration and are discussed further in the report, in particular in sections 4.2, 4.4 and 5.4.

3.3 PASSIVE MEANS FOR THE SAFETY OF THE DISPOSAL FACILITY

Russian Federation's position

The Russian Federation has stated the initial principles of establishment of the disposal facility, as well as all subsequent activities on injection, monitoring and control. The Russian Federation indicate that there is no real need to take active measures after the facility's closure, as the passive measures provided by the properties of the host environment were proven to be sufficient. There are regulatory requirements for monitoring that demand active measures during the period after the closure of the facility.

The safety functions of the disposal are implemented by active and passive safety means. The basic passive means for the post-closure safety are the following ones:

- Sorption barriers;
- Reservoir bed;
- Low-permeable horizons (aquitards);
- Buffer horizon.

Active measures are taken for achieving, maintaining and observing safety functions of the geological formation during the operational period. The main active measures focus on:

- Monitoring of conformity of the waste to the requirements (waste acceptance criteria), which is set for radiological basis and for gaining compatibility with the geological environment (physical and chemical and bacteriological properties), allow safe operation and decrease the possibility for irreversible undesired changes of rocks in the geological formation;
- Monitoring of observance of regulatory requirements on the injection mode (mainly temperature and pressure monitoring);
- Monitoring of conditions in observation wells;
- Closure of wells;
- Foreseen institutional control after facility closure.

Active measures to maintain the safety functions for the waste placed in geological environment are not required.

PRT observation

For geological disposal the requirement for passive safety focuses on the period after closure of the facility. The guiding principle is that geological disposal should be passively safe and that safety should not rely on long-term for monitoring or institutional control. This does not mean that post-closure monitoring should not be performed or that other institutional controls, like markers or land use control possibly promoting safety, should not be implemented and maintained.

In the concept of LWR injection DDF the passive phase starts at the time waste is injected and there is no actual need for active measures for safety assurance. The passive features and the characteristics of the disposal concept, make it difficult to retrieve the waste, or to implement corrective actions in case of deviations or some other safety significant observation, after waste has been injected.

From the documentation provided and discussions during the mission, post-closure monitoring is required by Federal Law as long as waste is hazardous (see section 5.3). Observation wells that penetrate different clay and buffer layers create possible route to radionuclide migration. The post-closure monitoring strategy should be developed in a way that the open boreholes do not inflict on post-closure safety, which means that during the phase of institutional control assurance of safety should not rely on active measures like observation well maintenance.

4. DEVELOPMENT, OPERATION AND CLOSURE OF A DISPOSAL FACILITY

4.1 INTEGRATED SAFETY DEMONSTRATION: SAFETY CASE DEVELOPMENT

Russian Federation’s position

The Safety Requirements on Disposal of Radioactive Waste [1] suggests that periodic updates may be warranted during the operational phase of a facility and prior to seeking a license to close the facility.

The safety case is in particular addressed through three requirements in [1] on the preparation, approval and use of the safety case and safety assessment for a disposal facility, on the scope of the safety case and safety assessment and on the documentation of the safety case and safety assessment.

The safety case is to contain a safety assessment that addresses post-closure safety criteria indicated in [1]. Requirement 26 of [1] applies to an existing practice. This means there needs to be an all-pathway dose or risk calculation to a representative member of the public in a location, or several locations, to test the robustness of the disposal system.

For an existing practice, the post-closure safety requirements may be restated as follows:

Calculations of disposal system safety ought not result in doses or risks that exceed the stipulated dose or risk to a representative person who might be exposed in the future as a result of possible natural processes affecting the disposal facility. The dose constraint is 0.3 mSv per year or a risk of about 10^{-5} per year. Note that this representative person is not a person drilling into the disposal facility, but may be adjacent to the facility using groundwater to grow food, for drinking and other purposes. An all-pathways biosphere calculation is needed to address this requirement, and such a calculation ought to be based on the best available scientific information, defensible modelling practices, and pertinent monitoring results.

In addition to these long-term natural-system evolution calculations, the potential dose-effects of inadvertent human intrusions after closure also need to be evaluated. If such intrusions are indicated to lead to a potential annual dose of less than 1 mSv to those living around the site, efforts to reduce the probability of intrusion or to limit its consequences are not warranted. However, if human intrusions are expected to lead to a possible annual dose of more than 20 mSv per year to those living around the site, there is a problem with the existing disposal facility and intervention of some type, to be proposed by the site operator, may be warranted. Probability arguments are, of course, allowed in carrying out such evaluations, but must be based on defensible information and data. Typically, a present-day biosphere is assumed, but this is up to the operator to define and defend to the regulator.

PRT observation

In the materials reviewed by the PRT, these two sub-requirements have not been addressed in a way that satisfies the intent of the Safety Requirements on Disposal of Radioactive Waste [1]. The information presented needs scientific argumentation to make it more credible and to bring it in line with the expectations given in [1] for a comprehensive, integrated safety case.

Paragraphs 4.6 through 4.11 of [1] discuss the nature of the safety case and safety assessment. The stated properties of the safety case and safety assessment in [1] need no modification to apply them to an existing practice, and are recommended for consultation.

In the materials provided for review by the PRT, Document C provides an overview of the structure of arguments for safety, describes what is considered to be the safety case and the safety assessment by the Russian Federation, and shows awareness of the Safety Requirements on Disposal of Radioactive Waste [1].

Document B intents to present a case for safety for the Severny liquid radioactive waste disposal facility. Document B assembles relevant information to set the stage for the working facility's safety arguments and addresses operational safety quite well. It also addresses some key aspects of post-closure safety for the Severny site, showing awareness of what is needed to meet the requirements for a safety case with a safety assessment given in [1].

Document B acknowledges the need for a comprehensive post-closure safety assessment. However, it does not describe such an assessment, nor does it present the results of such an assessment. This is a major shortcoming.

Document B presents a combination of qualitative arguments, in combination with conservatively calculated quantitative arguments, to address system safety. The PRT found that the qualitative arguments were not altogether convincing. They were claims and assumptions that may be correct, but without providing substantive evidence they are at best uncertain, and ought to be evaluated as modeling and data uncertainties. The quantitative arguments were useful indicators of aspects of system safety but not integrated into a comprehensive system safety assessment as expected in [1].

RECOMMENDATION

- In support of creating a safety case as required in [1], an integrated safety assessment must be completed based on the best available information and use defensible conceptual and mathematical models.
- The calculation endpoints must include either the reference individual dose or risk as defined in [1]. It is however also recommended that other intermediate indicators (e.g. concentrations, fluxes…) be considered.
- The level of technical support for assertions of fact needs more attention when a formal safety case is prepared in accordance with the expectations given in [1]. Specific instances where the PRT felt such support was lacking are discussed in the next sections.

4.2 SYSTEM DESCRIPTION

Russian Federation's position

The documents provided by the Russian Federation provide a comprehensive overview on the geological systems the radioactive waste is injected in. A common feature of all sites is the sequence of sedimentary layers consisting of higher permeable reservoir beds (injection layers) alternating with low permeable layers isolating the reservoir beds from each other. The reservoir beds contain medium grain sands and poorly cemented sandstones with subordinate sub-layers of clay rocks are identified within the reservoir beds.

The low-permeable aquitards comprise of various clay rocks interbedding with subordinate sand sublayers and sometimes limestone. A site contains several injection layers located at depth varying from 180 to 1550 meters. The principle approach is to inject higher activity wastes into the deeper layers whereas low level waste (LLW) is injected into the upper injection horizon.

The site characterisation programmes, started in the late 1950, comprises geological, geophysical investigations programmes followed by the drilling of numerous exploration boreholes. These field studies have been complemented by detailed laboratory-based investigation programmes defining the properties of the reservoir beds and aquitards in detail (mineralogical compositions, rock mechanical investigations etc.). According to the documentation provided a hydraulic testing and monitoring programme provided in depth information on the hydrogeological characteristics of the injection sites and adjacent areas.

According to the documentation, six conceptual requirements have been set out regarding the geological conditions appropriate for liquid radioactive waste disposal.

1. Isolation of the selected aquifers from shallow fresh water aquifers by low-permeable rocks;
2. Sufficient capacity of the selected aquifer in relation to filtration and sorption characteristics;
3. Presence of a buffer aquifer between the selected aquifer and the shallow fresh water aquifers;
4. Low natural underground water flow rates in the selected aquifer;
5. No discharge areas of the selected aquifers or active tectonic faults in the expected impact area of deep disposal;
6. No mineral deposits in the area of possible impact of deep disposal.

Based on this set of requirements for each site a large number of investigations were carried out, geological and hydrogeological model was constructed and the injection layers were selected.

According to the documentation presented these six requirements have been proven to be fulfilled for only these three sites. Specific emphasis was laid on the fact that there are, beside the geological characterization, supporting arguments that the different layers are hydraulically isolated from each other (age determination of different ground water level and hydraulic head differences). The regional structures and the continuity and homogeneity of the isolating aquitards as well as the absence of transmissive features (vertical faults) has been proven by the regional scale geophysical investigations and drillings even outside the potential discharge areas.

It is further stated that the currently existing geological and hydrogeological boundary conditions will not change for the time period of the potential hazard of waste.

The “Severny” DDF was selected as the reference facility for illustration of the conformance of liquid radioactive waste deep disposal technology to the IAEA Safety Requirements. It was selected for the following reasons:

- “Correctly average” characteristics of volume and activity of disposed liquid radioactive waste compared to SCC and RIAR, as well as timeframe of facility operation. At the same time, all types of liquid radioactive waste were present in the list of disposed waste over the time of operation;
- Presence of wide range of technological features (pressure injection, fill injection, relief wells, etc.);
- Geological and hydrogeological conditions similar to those at the SCC, but complicated by the tectonic disturbance and close vicinity of open hydrosphere (the Enisey River);
- DDF of SCC (site 18 and site 18a) are very similar to the “Severny”. These covers, primarily, similar mineralogic, filtration and sorption properties of reservoir beds and aquitards, flow rates and chemical composition of stratum waters. Second is the similar depth of reservoir beds. Relative similarity of liquid radioactive waste composition (in components) leads to similar physical and chemical processes.

The way to consider system description and related uncertainties is also addressed in the section on safety assessment (section 4.4).

4.3 WASTE INVENTORY

Russian Federation’s position

Any assessment of a disposal concept for radioactive waste needs to consider the specific boundary conditions, among others, the waste inventory. Ideally full inventories for past, on-going and planned injections should be presented as they form the basis for assessments and dose calculations.

VNIPIPT (Moscow) and IFH RAS carried out work on justification of volumes and compositions of waste subjected to disposal. ^{90}Sr and ^{137}Cs were considered to be the major radioactive waste components determining their potential hazard. It was also set out that uranium and trans-uranium nuclides as well as very-long-lived fission products should occur in very low concentrations.

Full information about the detailed inventory of injected (HLW, ILW and LLW) was not provided to the PRT due to confidentiality limitations. It was only possible to derive estimates for the injected waste based on the information provided in the presentations and in the documents sent for the preparation of the mission.

In the presentation during the mission, measurement values in the order of 10^9Bq/l of beta/gamma emitters (e.g. ^{90}Sr, ^{137}Cs) are reported. With regard to long-lived alpha-emitters, values of $1.3 \cdot 10^5$Bq/l for ^{239}Pu, $1.7 \cdot 10^2$Bq/l for ^{237}Np and $2 \cdot 10^4$Bq/l for ^{241}Am were provided. It was said that these values correspond to average concentrations of waste as of 1995. This average is taking into account all waste (i.e. LLW and ILW).

However, waste of such composition would not generate any significant heat. Since substantial heating of the waste has been observed, radionuclide inventory in the injected ILW must be substantially higher.

During the discussion of these issues, the Russian counterpart explained that the waste acceptance criteria provided in the preparatory documents can be used as a rough indication for the inventories in the injected waste.

Tables 7 – 9 of Document B list the waste acceptance criteria for the "Severny" DDF for different waste types. The following criteria are provided:

- For LLW activity of ^{137}Cs has to be lower than $1.85 \cdot 10^5$Bq/l and activity of ^{90}Sr has to be lower than $3.7 \cdot 10^4$Bq/l. The limit for alpha-emitters is 370 Bq/l;
- For acidic ILW, the total beta/gamma activity is limited by $2.96 \cdot 10^{11}$Bq/l. ^{239}Puis limited by 0.25 mg/l (which corresponds to 0.5 MBq/l) and ^{238}U by 330 mg/l (which corresponds to 4 kBq/l);
- For alkaline ILW, values are provided too. These are roughly one order of magnitude below the values for acidic ILW.

These numbers represent the maximum concentrations. Based on the statements made by the Russian counterpart, actual concentrations are usually within an order of magnitude of these numbers.

For the "Severny" site it was stated that about 2 % of the whole injection volume was comprised of acidic ILW and 40 % of alkaline ILW. The remaining 58 % were LLW.

It was mentioned that acceptance criteria for the other sites have been provided in the answers to the questionnaire and that these can be seen similarly as indication for the injected inventories.

The documents provided indicate that after the beginning of 2013 the injection of acidic has been stopped because this waste is no longer generated. This means that at the "Severny" sites in the future only LLW and alkaline ILW will be injected. According to the discussions this is also true for the other sites.

The Russian Federation explained that the activity concentration of some potentially significant long-lived nuclides other than given in the inventory list (^{14}C, ^{36}Cl, ^{129}I) is lower than the detection thresholds and substantially lower than the concentration limit specified for drinking water hence those have no long-term dose relevance. This fact has been confirmed by measurements of water samples taken from observation wells.

PRT observation

The assessment of longer term releases to potential discharge areas requires detailed knowledge of the radionuclide inventory injected. Any safety assessment of a disposal facility concept needs to consider the entire waste inventory, including long-lived radionuclides even if these are present only in minor quantities. In addition, to know the radionuclide inventory in the waste, it is also important to know other contents and characteristics of the injected waste (e.g. organics...) which can influence the behavior of the radionuclides.

The plume of long-lived transuranic radionuclides formed by ILW injection is likely to persist for thousands of years hence a reliable inventory of long-lived transuranic radionuclides and their daughter products is of great importance. The PRT considers that the overall approach for setting up a reliable inventory represents an internationally agreed practice.

Although it was stated that such comprehensive inventories do exist for the liquid waste injection sites, due to confidentiality reasons, a complete radionuclide inventory has not been made publicly available yet and so was not made available to the PRT. Therefore, any judgment of the hazard potential posed by the waste can only be based on rough estimates derived from the available information.

The radionuclide concentrations based on the Tables 7 – 9 in Document B appear to be reasonable and also can explain the observed heat generation.[1] Therefore, an indicative basis for the injected waste inventories exists. However, these cannot be seen as substitutes for detailed inventories for the waste injected over time at the different facilities.

RECOMMENDATION

- Full inventories of the radiological and chemical components for past, on-going and planned injections should be presented as they form the basis for future safety assessments and dose calculations.
- Uncertainties in the estimates of both material and radionuclides in the waste disposed of should be quantified.

4.4 SAFETY ASSESSMENT

Russian Federation's position

According to [1], radiation exposures for the public are a key indicator for post-closure safety. The approach described in the safety standards to assess the post-closure exposure uses scenarios for anticipated evolution of the system and possible alternative evolution scenarios. In addition, what-if scenarios can be used for performing sensitivity analyses on the importance of certain elements of the system (e.g. barriers) or assumptions made in the assessment (e.g. the importance of assumptions made for sorption).

Within these scenarios, potential radiation exposures of the public have to be analyzed with due consideration given to the uncertainties in scenario definition, site and waste characterization and modeling. For the deep well injection, a particularly important area of uncertainties which need to be thoroughly addressed relate to assumptions made with regard to the water flow paths and radionuclide migration.

Information Provided

[1]Assuming a β/γ activity of $3 \cdot 10^{11}$Bq/l a total annual energy of 400 kcal/l will be generated by radioactive decay (assuming an average decay energy of 1 MeV). This order of heat generated is consistent with heating up the waste to temperatures of a few 100°C so that the given numbers for the WACs seem to be consistent (in an order of magnitude sense) with the observed heat generation.

During the pre-mission in December 2012 it was agreed that detailed information is to be presented for one (so-called reference) site. For the other sites, only general information should be provided.

The following descriptions summarize the information which was made available for the "Severny" site.

Time Frames

In Document C, it is stated that, depending on radionuclide composition of the injected waste, the period of potential hazard of a facility will vary from 10^3 till 10^6 years. As an example, the time frame for modeling of ^{90}Sr migration is 750 years - the period of time corresponding to radioactive decay of ^{90}Sr to safe concentrations.

Normal Evolution

For the normal evolution scenario, some modeling results addressing the groundwater migration of the injected radionuclides based on the local hydrogeology are provided in the preparatory documents. These are based on a model which has been developed within the scope of an international project in the late 1990s.

A detailed description of the models used is not given in the documents made available for the preparation of the mission. It appears that these are mainly two-dimensional models making quite simplified assumptions with regard to the hydrogeological situation at the site. A full 3D modeling of the site area has not been performed yet but a model that would allow such an evaluation is currently under development.

The source term for the modeling was defined according to the information described in Section 4.3. A description of the further assumptions used for modeling the radionuclide migration is not provided in the documents.

Some further information was provided during the mission. The model uses a sorption equilibrium model for the radionuclide transport with generic k_d values.

With regard to the results, some indicative values for radionuclide travel times are provided. These state that waste plumes at the earliest would reach the site boundary after 1000 years for Aquifer I (used for ILW injection) and after 200 years for Aquifer II (used for LLW injection).

No further quantitative information (contaminant concentrations in groundwater and surface water at different locations, results of exposure assessments) has been made available. Instead, a qualitative description of modeling results is provided. This states that no significant influence on local rivers from the contaminant plumes would result.

Some further information was provided during the mission. It was explained that maximum doses over time from using the water of a local river have been estimated. These doses are at maximum in the order of a few tens of MicroSieverts per annum.

This conclusion mainly relies on the following assumptions and modeling results (which basis is only partially provided in the documents):

1. No connection between the two aquifers used for injection and to the topmost Aquifer III (which not has been used for waste injection) is assumed to be present in the area of the waste injection;
2. Towards the border of the allotment area, connections between the aquifers are assumed and a partial discharge of the radionuclides into the local rivers is assumed;
3. The retention of radionuclides by sorption and the calculated travel times play a key role in the assessment of this scenario because these lead to a substantial reduction of the radionuclide concentrations in the river water through radioactive decay;
4. There is no consideration of processes such as colloidal transport of radionuclides which cannot be ruled out to play a role based on current knowledge. However, the Russian Federation considers that assessments of radionuclide migration are still conservative ones. Also, the possible influence of knowledge which has been gained since the modeling was performed is not considered (e.g. on geochemical processes taking place in the injection zone) in the documentation provided but it is currently being taken into account during the development on the new 3D model.

In conclusion, the answer to the IAEA Questionnaire states: "*Under the current best understanding of site conditions, there is very little likelihood that the injected wastes would reach the earth's surface prior to the time that the radioactive materials had been absorbed, decayed, or dispersed to concentrations far below standards set for drinking water*".

The only relevant exposures are said to arise from human intrusion (use of groundwater as drinking water). Quantitative values are provided in the alternate scenarios (see below).

Alternative Evolution

A screening of features, events and processes (FEPs) which could lead to deviations from the normal evolution scenario is provided in a number of Tables in Document B. However, it appears that these FEPs relate to deviations from normal condition during the operational phase. A complete and systematic analysis of FEPs relating to the long-term evolution of the facility has not been provided, although some of the FEPs also are relevant for the long-term evolution.

The statements given are qualitative and many FEPs have been ruled out on that basis. There is no indication that further efforts have been made to investigate and demonstrate the validity of the statements made or that attempts have been made to systematically identify all FEPs which are relevant for the long-term evolution.

A few alternative post-closure scenarios have been mentioned and partially analyzed. These are not directly derived from the FEP screening.

The alternative scenarios address changes in the groundwater flow paths compared to the normal evolution scenarios, changes caused for different reasons including defects of the sealing layer between the aquifers (e.g. through a degradation of a borehole sealing or through leaving an unsealed borehole).

Another scenario addresses a failure of the fault zone. This scenario appears to address the possibility that the currently low hydraulic conductivity is changed through some tectonic processes. In addition, this scenario is also explained to take the observation at some monitoring wells into account that there seems to be water flow crossing the fault zone in a specific location.

For these scenarios, no exposure estimates are given.[2] Only qualitative discussions of their effect are provided.

Additional scenarios for intrusion into the "Severny" site by using water from Aquifers I and II at different points in time have been set up and dose estimates (only for drinking water, no agricultural pathways) are given. This can result, according to the calculation results, in unacceptably high radiation exposures. Doses from the use of water from Aquifer I as drinking water can be as high as 20 Sv/a and for Aquifer II a maximum dose of 7 mSv/a is calculated.

The discussion states that these numbers have been calculated based on conservative assumptions related to the source term and the radionuclide migration. It is further said that institutional control will ensure that such drilling for water does not take place in the immediate period after closure. However, it is appreciated that in the long term the institutional control may fail. But it is stated that even in this case such a scenario is very unlikely because the yield of Aquifers I and II was only sufficient to support small wells for the supply of a small community and that for this purpose it would be much more likely that the overlying Aquifer III is used.

Research work has been executed in studying colloidal and pseudo colloidal forms of radionuclides migration, distribution of the basic radionuclides in liquid and solid phases of reservoir beds and confining layers in the vicinity of injection wells, and radionuclide capture by microbes. Potential effects of these processes have not yet been addressed in any quantitative scenario.

Presentation and Analysis of Results

Results are not presented completely in the documents (which certainly at least partially is due to the limitations for preparing the documents for the peer review).
The results presented refer to different situations. Some represent expected values, others are worst-case considerations. It is not always clear which level of certainty is assigned to the different results.

PRT observation

The following discussion relates only to the "Severny" site because only for this site a detailed description and quantitative results have been made available. Therefore, no comments can be made on the status of the safety case development and on the actual safety of the other facilities.

Time Frames

The PRT considers that the consideration of longer timeframes than initially used (from 1000 years to 10^6 years) is reasonable according to the characteristics of the radioactive waste, which goes in the direction of applying a graded approach.

However, [1] warns against seeking to go out too far in terms of future time in its paragraph 2.16:

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[2] For the fault failure scenario, a table with dose results from drinking water from Aquifer I is given. But the numbers are identical to those provided earlier for the corresponding intrusion scenario. Also, there is no reason to think that a failure of the fault zone would change these intrusion doses. Therefore, this table apparently is inserted by mistake.

"It is recognized that radiation doses to people in the future can only be estimated and that uncertainties associated with these estimates will increase for periods farther into the future. Caution needs to be exercised in applying criteria for periods far into the future. Beyond such timescales, the uncertainties associated with dose estimates become so large that the criteria might no longer serve as a reasonable basis for decision making."

In view of such sound advice, it is highly desirable to state a time limit, a period of concern, and to back that stated time period with some sensitivity analyses that suggest the time of peak potential risk is past at the stipulated point in time.

Arguments for a time cutoff for the safety assessment ought to be made and supported based on potential risk-versus-time arguments of this nature. A million years may be well beyond what is needed to evaluate safety for the type of disposal facility under consideration in this peer review. Rather than basing the timeframe of interest on the half-life of the longest lived components of the waste, it may be advisable to base the timeframe on the occurrence of a period of peak potential risk from the facility.

Tables such as 4.6 and 4.7 in the presentation "Post-Closure Safety" may be useful when supporting an argument for a time cutoff.

Normal Evolution

The modeling performed within the normal evolution scenario as well as the results obtained are not described in a systematic and comprehensive way in the documents made available. It is appreciated that this is partially due to limitations existing for the preparation of the mission.

Since only limited information about scenario definition, data and assumptions used and results obtained is provided, it is only possible to issue some general comments:

- There are apparently some deficiencies in the site characterization which have a potential effect on the validity of the assessment results. Important examples concern

    - the possible existence of high permeability layers in the aquifers;
    - the potential for vertical movements of groundwater through potential vertical interconnections between the two aquifers (in particular from Aquifer I upwards), which also takes into account the expected conditions of the boreholes in the long term;
    - the potential of the discharge of Aquifer I groundwater to the Bolshoi Tel River;
    - the possibility for hydraulic interconnections through the fault zone leading to a westward groundwater flow (an "anomaly" of measures at some monitoring wells seems to suggest that this possibility exists).

  In order to arrive at a normal evolution scenario which can serve as a sound basis for the safety case, these and other uncertainties about site characterization and input data need to be resolved and appropriate justification for input data and assumptions are to be provided.

- It is unclear whether the hydrogeological situation is described adequately in the models even though the current simplified two-dimensional models were calibrated against site characterization data. The models provide only a two-dimensional description of the water flow and contaminant migration. In view of the complexity of the site it appears to be necessary to set up a full three-dimensional representation of the hydrogeological regime at the site covering the whole area from the injection locations to the groundwater discharge locations. This model should be calibrated and validated to the extent possible using results from earlier site characterization (e.g. the performed pumping test) as well as from current monitoring and considering the recommendations issues by the national group of experts about the improvement of the flow and migration modeling of Severny site. Geochemical processes play a key role in the overall concept. In particular, geochemical processes leading to a long-term immobilization of radionuclides through the formation of minerals have been discussed but not have been accounted for in the models. In view of the importance of these processes for the overall situation, a geochemical model should be developed which adequately reflects these processes instead of the currently used quite simplified equilibrium sorption model.

- All parameters and assumptions used for the geochemical model should be thoroughly justified based on laboratory and field data. For this, the currently ongoing experiments on the stability of radionuclides in the minerals formed after the injection can be used as an important basis. This requires, of course, that these are conducted and evaluated in a way to provide clear evidence for the long term geochemical processes that can be expected.
- The possible impact of colloids on the migration of radionuclides needs to be addressed.
- With regard to the long-term borehole sealing, qualitative statements were made that the selection of cement ensures its long-term stability. This statement appears to be based on qualitative arguments (e.g. that the cement used is produced using the local limestone). There is no conclusive analysis proving the long-term stability. This aspect should be addressed in defining assumptions for the normal evolution scenario.
- Not all possible exposure pathways have been taken into account. The use of water for agricultural purposes (watering of cattle, irrigation of fields or private gardens) needs to be addressed in order to obtain a complete picture of possible radiation exposures.
- Results should be provided in a clear and complete fashion. All relevant exposure locations, exposure pathways and time frames for the exposure should be clearly identified and results for radionuclide concentrations and radiation exposures should be given. Since it is difficult to interpret the meaning of statements such "traces of long lived RN" or "minor content of" etc., quantitative results should be presented for all relevant aspects.
- Uncertainties need to be clearly identified and taken adequately into account.

Alternative Evolution

A general criticism with regard to the alternative evolution scenarios is concerned with the approach chosen to define the scenarios to be considered. The safety case needs to demonstrate that the overall set of scenarios provides an envelope for all perceivable modes of site evolution and takes into account all features, events and processes (FEPs) which could have implications for safety. This requires defining alternative evolution scenarios and their assumptions in a systematic and transparent way.

One option for doing this, which is applied in similar projects in many countries, is a systematic analysis of FEPs. After a screening of which FEPs could be potentially relevant, scenarios are developed which cover all relevant FEPs.

Such a systematic FEP analysis has not been performed with regard to the long-term evolution of the facility. The analysis provided in Document B mainly addresses operational aspects and only some long-term aspects are analyzed. Furthermore, the reasons for excluding certain FEPs do not appear to be sufficiently justified in all cases. And, lastly, the results of the FEP analyses are not consistent with the actual definition of alternative scenarios. As an example, the analysis states that vertical migration of waste between the different aquifers is impossible. This is obviously not correct and an alternative scenario has been defined which addresses this type of situation.

When systematically defining scenarios, it is of importance to define which scenarios are considered to describe alternative evolutions of the site or in its surroundings which are believed to have some likelihood of actually occurring. These need to be distinguished from what-if scenarios which are not believed to realistically occur and which are defined to test the importance of certain elements or the robustness of the disposal system and/or of the safety demonstration.

The defined scenarios do not appear to be complete in this sense, at least no justification is provided that all potentially relevant features, processes and events are considered. Also, there is no clear distinction between alternative and what-if scenarios.

In summary, the recommendation arises to perform a systematic and complete analysis of all features, processes and events which could have implications on safety and use this for a comprehensive and complete definition of alternative and what-if scenarios.

The description of the defined scenarios is, as in the case of the normal evolution scenario, not performed in a systematic and comprehensive way in the documents made available. Therefore, it is again only possible to issue some general comments:

- The already discussed deficiencies in the site characterization also have impacts on the definition of alternative scenarios. To the extent that uncertainties are not be reduced by further site investigation, it must be ensured that these are taken adequately into account in the definition of alternative scenarios;
- The limitations mentioned with regard to the modeling also apply to the analysis of the radionuclide migration and exposure assessment for the alternative scenarios;
- Similarly, remaining uncertainties about geochemical processes also relate to the modeling within the alternative scenarios. The uncertainties which remain after the further analysis, experiments and field investigations need to be taken into account in the scenario definitions;
- It is questionable whether the scenario allowing for an interaction between Aquifer I and II covers the potential effect of a long-term degradation of the concrete in the borehole sealings because this could affect all borehole sealings and not, as assumed in the scenario, just one borehole;
- A further important assumption concerning the scenario considering unsealed boreholes is related to the distribution of hydraulic head in the aquifers. Data which have been made available during the mission suggest that the hydraulic head in Aquifer II is smaller than in the other aquifers, so that flow from Aquifer I and Aquifer III would be directed into Aquifer II in case of hydraulic interconnections. This would have the important consequence that, even in the case of open boreholes or the degradation of the borehole sealing, no contamination of Aquifer III would result. The assumption of lower hydraulic head in Aquifer II is based on observations of the monitoring (only an example of these results for

one monitoring well was made available during the mission). In view of the importance of this assumption for the overall situation, it needs to be thoroughly justified. In particular it needs to be shown that this assumption holds for the whole area in which boreholes or natural flowpaths could lead to contaminating Aquifer III and it is further necessary to provide evidence that no change of this situation is to be expected after closure including the long term.

A scenario of particular importance relates to possible extraction of groundwater from the contaminated aquifers and its use as drinking water, which can result, according to the calculation, in unacceptably high radiation exposures.

Evaluating the results achieved for this scenario several issues are to be considered:

- The documents provided only show the results for the maximum dose. This is not sufficient to develop an understanding for the importance of this scenario. In the presentations made, however, more detailed information was shown. The key result from this is that substantial doses from the groundwater extraction could occur over very long-time periods and that a large area could be affected. For example, for the time of 10,000 years, doses above 10 mSv/a are calculated even beyond the Bolshoi Tel River. This means that the use of groundwater from the lower aquifers may give rise to substantial radiation exposures in a quite large area in the order of 100 km^2. In order to provide a better understanding of the situation, the potential radiation exposures should be clearly provided as a function of time, location and contributing radionuclides.
- Obviously, uncertainties in the modeling also affect the interpretation of these results. From the discussions it appears likely that improvements of the data basis and models will lead to lower dose estimates. However, this needs to be demonstrated before the safety case can take credit from this.
- The reason given in the document and the discussions for the unattractiveness of the lower aquifers for the water supply is that overlying aquifer is easier to drill into and so is a much more likely source for a community water supply. However, the validity of this argument depends on several aspects requiring more detailed investigation and justification in the safety case:
    - It must be established that a more attractive source for drinking water in the form of an overlying aquifer with sufficient yield exists in the whole area which could be affected. Since in particular small community wells would normally be drilled at the location of the community to avoid the construction of pipes for transporting the water from other locations, it is important to establish the existence of more attractive water sources as a function of location in the affected area.
    - In addition, convincing evidence has to be given that the more attractive water supply will be available also in the future in the whole affected area. In this context, it seems that an effort to look at Quaternary water-levels in the area of interest could be used to show that there is no real likelihood of the upper aquifers drying out in a future-climate scenario, forcing humans to reach deeper for water.
- If such evidence can be provided, it can be argued that this scenario then becomes a “what if” type of calculation, i.e. a worst case situation which is not expected to practically occur. In this case it should be made very clear that it is a speculative calculation not in conformance with what scientific work suggests is likely to happen in the future. Without such a well stated context, results of this nature undermine the safety case.

Presentation and Analysis of results

Results are put into perspective through qualitative discussions in the documents. This is valid and necessary. But the statements made need to be defendable. Therefore, in particular arguments meant to reduce the level of significance which is assigned to exposure estimates need to be carefully justified and each argument used needs to be backed by supporting evidence.

Although showing results of very conservative calculations has some value, that value would be greatly enhanced if shown in the context of what may more reasonably be expected. That approach gives an indication of the likely safety impact, and then an indication of what that impact cannot exceed.

A better approach, and more in conformity with [1], may be to show a comprehensive safety case result with a statistical interpretation, suggesting a mean dose or risk, and 95th percentile values in both directions, for example. This is most easily done using a stochastic modeling approach but can also be done using a deterministic approach with illustrative input-value cases representing input-data distribution probabilities.

This approach of showing what is likely, or expected, and then perhaps what the upper bounds are, is of particular importance when showing likely drinking water doses from the rivers into which contamination is likely to eventually discharge. One way to build opposition to a practice is to present only conservative, meaning unrealistically high, potential impacts. Stakeholders are entitled to impact assessments that reflect what is likely, with some bounds reflecting modeling and data uncertainty. Unrealistically high impact predictions serve no positive purpose. If they are shown at all they ought to be accompanied by more realistic estimates, a discussion of uncertainties, and of the more likely range of outcomes.

With regards to the evaluation of the results, the dose estimates presented in the normal evolution scenario are in compliance with the 0.3 mSv/a dose constraint stipulated in [1]. From this perspective, continuation of the injection practice would be acceptable.

However, as stated in the previous sections, there are several issues to be addressed before this dose estimate can be seen as a sound basis for the safety case supporting the injection practice.

A further requirement in [1] is to address the intrusion issue. The results provided for this are partially extremely high and substantially above the thresholds provided in [1] of 1 mSv/a to start thinking about a reduction of intrusion probability and of 20 mSv/a to start thinking about an alternative disposal concept.

The above discussion shows that several aspects of these calculations require further consideration. It will only be possible to evaluate compliance with this criterion in [1] after further insight into the basis for this scenario and the probability of its occurrence has been reached.

RECOMMENDATION

Specific recommendations can only be made for the “Severny” site:

- The documentation of the safety assessment should be such that all input data and assumptions used in the scenario definition and the modeling are provided and justified.
- It is recommended to perform a systematic and complete analysis of all features, processes and events which could have implications on safety and use this for a comprehensive and complete definition of normal evolution, alternative and what-if scenarios. For this purpose, additional characterization work may need to be done (e.g. related to the integrity and spatial extent of aquitards and the stability of newly formed clay phases) to reduce the level of uncertainties.
- All scenarios should be based on a sufficiently complete understanding of all relevant site features and should use adequate models which are capable of representing the relevant site features and processes. Uncertainties need to be clearly identified and taken adequately into account.
- Conservative calculations ought to be replaced with results from models that include more realism, and ought to be used with caution and properly labeled to indicate they are unlikely results if they are to be used at all.
- For the other sites a similar scenario analysis will have to be performed. Many comments and recommendations made here with regard to the systematic approach required in this context will also apply to the other sites.
- After resolving the issues addressed in the above recommendations, compliance with the dose criteria provided in [1] should be evaluated.

The further development of the safety assessment according to the above recommendations should be used as basis for the development of a closure plan. The most important questions to be addressed in developing such plan is whether the planned borehole sealing is sufficient or whether further measures to protect people from unacceptable radiation exposures have to be considered. The answer to this question can only be found and justified based on a thorough analysis of relevant scenarios.

4.5 OPERATION

Russian Federation’s position

Generalities

General operation of liquid radioactive waste DDF was regulated through: mandatory annual reporting to and scientific support from the design organization and competent scientific research organizations (VNIPIPT, IFH RAN, Gidrospetsgeologiya); regular control by supervision bodies (Special Department of the Ministry of Health, Rostechnadzor, Rosprirodnadzor); regular reviews by international commissions.

The report submitted to the PRT presents the internal organization put in place (number of personnel, skills, etc.) by the different operators of SSC, MCC and RIAR facilities to operate the injection of liquid radioactive waste.

Operation of DDFs is supported by regular monitoring observations of the condition of the geological environment migration of disposed waste, of changes of the pressure mode in aquifers, of composition of stratum fluids, of changes of physical fields on the surface and in the wells, and the technical state of wells and surface equipment. These observation results are used for: monitoring of filling of reservoir bed with liquid radioactive waste components and the extent of their localization; detection of the prerequisites for incidents and accidents; optimization of operation modes (mainly injection pressure); improvement of the knowledge of processes triggered by liquid radioactive waste disposal and models of the geological environment; and assessment and justification of the safety of disposal.

In parallel with the operation of DDF, specific scientific studies were performed to specify data on the processes in reservoir beds triggered by liquid radioactive waste disposal. Experiments were carried out for pressure and temperature values in the reservoir beds which are typical for disposal of technological (alkali and acidic) and non-technological waste. Processes occurring in the vicinity of injection wells and in remote sections of the stratum as waste spreads in the reservoir bed were studied.

Safe operation of the facilities is ensured by implementation of organizational and technical measures. Safe management of DDF's operation is based on monitoring the parameters of the facility with account for their specification as new data on the functioning of the system becomes available (reduction of uncertainties, improvement of understanding). Analysis of monitoring data has given new insights to specify the parameters characterizing the geological conditions of the environment, physical and chemical processes, accompanying waste migration.

Lessons learnt from operation practices

Document provided for the purpose of the peer review present in particular the most essential situations which analysis has demanded changes of designs, technologies, and standard operating procedures or supporting works. These situations included deviations, violations and emergencies, which took place mainly during the trial operation period. In all cases, they did not lead to contamination of territory outside DDF site and the allotment area. Adaptations and improvement of the operation mode concerns mainly: change of injection well design, enhanced quality control of the waste, adaptation of injection modes and surface utilities. Following examples related to the SCC facility were presented by the Russian Federation.

1. Change of well design: during experimental operation (1963-1965), penetration of waste into a buffer layer was detected. Leakage was quickly detected by reaction of underground waters levels in buffer horizon (measurements were performed on a daily basis). A specialized inspection showed rocks softening of reservoir bed because of intensive pumping out of the underground waters during preparatory works on development of a well screen zone in the course of well construction. The inspection of other wells and repair work on consolidation of the cement stone in the annular space were conducted. Besides, the injection well design was changed, namely:

a. The type of used steel for operational and filter casings was changed that enhanced the corrosion resistance of wells;
b. ‘Blind’ tubing casing was added to the design of wells for "acidic" waste disposal that allowed carrying out control measurements using the methods of temperature logging and gamma-ray logging directly in an injection well;
c. The limit pressures at well cap of injection wells were reduced from 25 to 20 bars that decreased a probability of vertical overflows;
d. “Blind” monitoring wells (without filters) were drilled at a distance of 20-25 m from injection wells to check the conditions of reservoir bed using geophysical methods that allowed observation of the process of reservoir bed filling, parameters of its heating, integrity of operational casings of injection wells and quality of operational and overlying horizons separation.

2. Enhancing the quality control of the waste: During the trial operation at the experimental (pilot) facility 18a of SCC in 1963, the injection of waste was made from storage pools. As a result, an intensive gas emission from an observation well took place that led to the emission of gaseous radioactive components and contamination of area with the surface less than 0.1 hectare. Dedicated investigations revealed that the gas emission was caused by the denitrifying bacteria activity. The bacteria activity in the storage pool was suppressed by a high salt concentration of waste. In the reservoir bed where waste containing nitrates was dispersed, the activity of bacteria intensified. The process dynamics (intensive gas emission from the well) was connected with formation of a "suspended" sandy plug interfering the uniform degassing of the bed. Cleaning of the sandy plug and dismantlement of wellhead were performed at that well. This experience was taken into account, and a scheme of waste preparation at the basic site of waste manufacturers, their transportation and injection into reservoir bed bypassing storage pools were ensured in design of all industrial liquid radioactive waste DDF. This allowed improving monitoring of conditions of waste directed to disposal.

3. Changes in injection modes: In 1973 at the DDF "Severny" (MCC) an intensive spread of a waste, exceeding the forecast, was detected in the reservoir bed of horizon II. Such waste spreading contradicted the accepted representations about waste behavior and about nuclides retention by rocks. The studies showed that it was caused by formation of an excessive permeability zone as a result of excess injection pressures that were close to or above the pressure of hydraulic fracturing of the rock. Adaptation of the injection mode was made by reduction of the injection pressure at wellheads and by defining a “ring in shape” zone of injection allowing a larger volume of reservoir bed to be used during injection activity.

4. Enhancement of surface utilities: During experimental and trial operation of SCC DDF, a number of pipeline leakages, leakages of fittings, valves and connections, spills of contaminated samples occurred. All these incidents did not lead to contamination of objects outside the sanitary protection zone (SPZ) of the DDF and did not create preconditions of such contamination in the future. However, mitigation of such phenomena impact in the period of active operation was ensured by placing special trays for pipelines, drains and leakage collectors.

PRT observation

The documentation reviewed by the PRT presents many elements related to the management of the injection operation with focus on the monitoring that allows checking the proper functioning and identifying deviations in the process. Several examples are provided with a special emphasis on how feedback from past practices has been used to enhance operation conditions. **The PRT is of the opinion that the general principle of iterative and optimization approach in the management of operating modes reflects a satisfactory control of the practice.**

The PRT highlights the fact that general background of the [1] (see paragraphs 1.17 to 1.21) as well as the requirement 11 about the step by step development and evaluation of disposal facilities support the idea of a phased operation of a disposal facility. A phased approach allows future generations to benefit from the experience of the present generations in designing a new radioactive waste disposal facility, without impairing their possibility of choice of technical solutions for operating and closing that disposal facility. A disposal facility should therefore be designed so as to ensure its long term safety (meaning that all aspects of safety have been studied and that appropriate techniques for closing the disposal facility have been qualified), but allowing future generations to eventually decide between three basic options: retrieve the waste if some unexpected behaviour would seriously impair the safety of the disposal, extend the period of opening of the disposal facilities through possible maintenance operations, close partially or completely the disposal facilities. The proposals for closure of the disposal facilities have to be optimized and should indicate how assurance and verification will be provided to guarantee that the closure will finally be performed as planned, in line with the elements given in the safety case. Thus, a phased approach of disposal offers time for taking appropriate decisions regarding moving forward to the next step, going backward or standing-by while awaiting additional information; it provides in particular elements of verification that the facility is behaving as expected. This last point is a key element which progressively enhances the confidence that one may have in the safety assessment of the disposal facility.

The PRT considers that there is no major gap identified in the safety approach related to the operation of the injection practice. In particular an emergency plan exists, lessons drawn from the experience gained since the beginning of the practice provided valuable enhancements of injection mode and control, and the management system for the operation of the injection practice seems to be adequate and does not call for any specific remark.

Nevertheless, the practice of direct injection in a natural geological medium makes it difficult to apply the above phased operating approach in case of an unexpected evolution of the system. The complete retrieval of the liquid waste from the reservoir bed is simply not practicable.

4.6 CLOSURE

Russian Federation's position

The Russian Federation has explained in documentation provided to the PRT plans for continued injection practice and foreseen time schedule for surface facilities decommissioning which is seen to be followed by disposal facilities closure. In the documentation provided for the PRT, the Russian Federation has explained requirements concerning closure planning and design. The Russian Federation states that facility closure is carried out so as to of prevent any impact of liquid radioactive waste on population and environmental media during the entire period of liquid radioactive waste potential hazard.

Decommissioning and closure of liquid radioactive waste DDF will be performed in accordance with the special design agreed and approved in accordance with the effective regulations. Design documents will be developed at the final stage of DDF operation, but before its shutdown. Scientific studies on preparation to decommissioning aimed at provision of input data for design works shall precede the development of the design.

It is considered that no special measures are required for limitation of migration of waste components in the reservoir beds and the buffer aquifer, as the characteristics of the reservoir bed and the properties of rocks preliminarily defined in geologic survey works provide localization of waste within the specified allotment area boundaries. But the detailed planning of closure procedures is to be developed. Specially developed and tested technologies for well conservation shall be used, providing bringing the wells into a technical condition that assures reliable separation of all the aquifers the well is drilled through. As described in the documentation the main part of closure is focusing on well closure, because they are potential connection channels between the reservoir bed and surface and overlying horizons. In the well location, conditions close to natural (before drilling) should be recreated.

Special materials, which promise stability in natural conditions of the geological formations should be investigated for use in conservation of wells. A special tested technology of plugging-back of well should be used with care being taken to assure a high quality of work.

Currently a specific closure plan, specifying the requirements and including a detailed documentation of the design and engineering procedures does not exist. For the extension of the operational license the general closure concept outlining an overall approach is sufficient and was approved by the regulatory body.

According to the information provided during the review a detailed closure plan will be developed at late stages of the facility operation assumed to be around 2025. It will include the documentation of preparatory measures, process solutions, labour protection and safety measures, evaluation of cost of works, as well as other sections required by regulatory documents for development of design documents.

The procedures (and requirements) to be applied for closing the boreholes will depend on the type of borehole (e.g. observation or injection wells) and on the conditions of the borehole encountered at the time of closure. In order to assess the closure concept, the expected time for closure structure to be performing effectively should be defined.

The Russian Federation has stated in the self-assessment questionnaire that delay in final closure of wells for 200 years or less does not have effect on safety. During the operation wells are sealed with plugs that isolate wells from biosphere. According to the questionnaire the degradation time for these plugs is comparable to the degradation of well metal tubing.

The Russian Federation has described in the documentation requirements arising from Federal Law. According to information provided to the PRT the Federal law includes the following provisions for closure:

- Activities involving construction, operation and closure of disposal facilities require a license for subsoil use and a license for the right to work in the field of atomic energy use (article 13);

- Operation and closure of LRW disposal facilities is executed by the National Operator for RW management appointed by the Government of the Russian Federation (article 20);

- Decisions on closure of LRW disposal facilities are taken by the Government of the Russian Federation (article 5);

- Safety requirements for RW disposal facilities, including safety assurance at the closure stage, and content and structure of the plans for closure of LRW disposal facilities shall be set by the federal codes and standards regulating radioactive waste management (article 8).

PRT observation

The documentation describes the legislative development that the Russian Federation has followed through regarding radioactive waste management. The law includes general provisions regarding closure planning and responsibilities regarding closure phase.

The documentation provided outlining the procedures to decommission surface installation of the injection site do seem to be sufficient to ensure a safe closure of the facility.

The concept of liquid radioactive waste injection requires numerous boreholes which are potential direct pathways from the disposal area to the biosphere. Open boreholes or connections through leaking closure structures may cause significant risk for radiation doses exceeding given limits and might lead to restrictions for the site use. A leaking borehole is also able to jeopardize several or all safety functions of the disposal facility.

Insofar the closure concept of boreholes is one of the critical elements for assessing the overall system behavior. The Russian Federation has recognized the importance of closure issues and raised the development of closure plan and design as one the topics requiring further development.

However, the general closure concept as documented and presented to the PRT does not reflect the importance of the borehole closure with regard to assessing the overall system behavior and providing input for safety assessment.

The documentation that the Russian Federation has presented to the PRT does not describe the requirements, the detailed design for closure structures and assumed their long-term performance. Thus, it is not possible to review the closure concept and if for example the uncertainties related to closure performance has been taken into account in safety assessment.

The PRT noted that some injection-, exploratory-, and observation boreholes have already been closed, some of them at very early times of the operational phase of the facility. According to the information provided these boreholes have been closed in compliance with the requirements as defined in the regulations for closing industrial boreholes. The question whether these (closed) boreholes will meet the requirements for the final closure of the facility (still to be defined by the regulator) remains open.

Further the PRT is of the opinion that the outlined control measures, such as monitoring temperature or hydraulic heads in the overlying aquifer are not sufficient for proving that the borehole closure will fulfil the assumed safety functions specifically for longer time scales.

In the documents it is stated that at facility closure a number of boreholes will remain open for monitoring purposes. The possible safety impact of these open boreholes has not been addressed in detail in the documentation provided. Time period limits on monitoring were not discussed, at least not in such a way that the reader could recognize such a specification.

Further the rationale behind and the issue whether the disposal is based on passive safety or on active institutional control (after closure) remained open.

In conclusion the general closure concept as documented and presented to the PRT does not reflect the importance of an efficient borehole closure. The main drawback of the lack of a detailed closure concept (one key element providing long term safety) is that the assessment of the system robustness – heavily depending on the functioning of the borehole closure – was not presented to the level required for a full assessment. Thus, it is recommended to concentrate on the development of a detailed borehole closure design.

- A set of design requirements related to the safety functions for the different borehole types should be developed. Further R&D and engineering work to specify and reduce the uncertainties (e.g. prove of emplacement quality, long-term behaviour) should be carried out and a demonstration of at least one possible closure concept, meeting the required performance criteria is recommended.

- For those boreholes already closed, options for inspections for checking if the performance criteria are met, should be developed. According to requirement 26 of [1] *"... measures shall be put in place to upgrade the safety of the facility, economic and social factors being taken into account..."* to meeting the requirements need to be considered.

- The evolution of closed boreholes for both, the normal evolution and a degradation scenario needs be taken into account in the safety assessment.

- The current level of safety case development does not allow deciding whether in addition to the sealing of the boreholes further remediations are required. Therefore, the possibility exists that the closure concepts would have to be expanded depending on the further assessment of long term safety.

RECOMMENDATION

The IAEA requirements [1] (paragraph 4.38) assumes that closure has to be considered in the initial design of the facility, and plans for closure and seal or cap designs have to be updated as the design of the facility is developed.

The PRT acknowledges, that initially the deep injection practice was commissioned in a time when there did not exist international requirements. However, a detailed closure plan and design should be developed to enable assessment of their performance as part of disposal facility post-closure safety assessment.

Thus, the PRT recommends that the Russian Federation demonstrates that at least one technical closure solution can be implemented with the appropriate performances to limit the release of radionuclides on a timeframe commensurate with the potential hazard of the waste. This demonstration should in particular rely on:

- A set of design requirements related to the long-term safety functions for the different borehole types;
- a R&D, engineering and modelling program aimed at qualifying the design and at identifying the set of remaining uncertainties;
- the update of the safety case and safety assessment to demonstrate, on the basis of the assessment of normal and altered evolutions of the boreholes, the safety of the overall disposal system. This demonstration should also take into account the performance of the already closed boreholes. If necessary, as stated in requirement 26 of [1] *"…measures shall be put in place to upgrade the safety of the facility, economic and social factors being taken into account…"* need to be considered.

5. ASSURANCE OF SAFETY

5.1 LIMITS (WAC), CONTROLS AND CONDITIONS

Russian Federation's position

In order to ensure the safe operation of liquid radioactive waste disposal facilities limits, controls, conditions were set. These were mainly based on physical and chemical studies conducted to determine the conditions needed to ensure the compatibility of waste with the geological environment.

A set of requirements for liquid radioactive waste pretreatment technology were developed to ensure that the limitations are met, including separation of suspended mater by filtration, chemical pretreatment of waste, periodic preliminary treatment of the well screen zone of the injection wells.

Various experiments under static and dynamic conditions were performed with the use of rock samples, collected during well drilling. The primary objectives included ensuring nuclear and radiation safety and inhibit of excessive gas and heat generation (layer heating).

Aiming at ensuring stable operation of injection wells minimization of clogging of reservoir bed pore space with fine-dispersed solid substances contained in the waste or generated as the result of waste interaction with the rock have to be guaranteed.

Based on the operation experience, the limit pressures at well cap of injection wells were reduced from 25 to 20 bars that decreased a probability of vertical overflows.

The operation life of the injection wells was defined that limits its operation by a number of disposed wastes and time of injections. Lifetime of the injection wells is 5-yr injection of acidic ILW and 10-yr injection of alkali ILW. The injection wells can be further used pending the results of the aging investigations.

Radiological capacity of DDFs is set by the regulatory body for the licensed period by regulating the volume of injected waste and the allowed concentration of radionuclides set out in the acceptance criteria. Limitations for annual volume of waste injected are the following: MCC – not more than 100 000 m^3, SCC – not more than 1100 000 m^3, RIAR – not more than 60 000 m^3. Injection rate is limited for ILW and LLW as 300 m^3 / day and 600 m^3 / day, respectively.

PRT observation

Based on the documents and information provided to the PRT all operations and activities important to the safety of the disposal facilities are subject to limitations and controls. Facility-specific criteria established by the regulatory body were not provided.

Although information was not included in the package of documentation available to the PRT about the emergency measures to be taken if problems were to arise when injecting waste, during the site visit it was explained that emergency plans are also put in place.

It was reported that there were operational difficulties at the beginning of the injection operations ((pipeline leakages, leakages of fittings, valves and connections, spills of contaminated samples) but based on the operational experience modifications and optimizations were carried out which resulted in a reliable routine operation.

The PRT is of the opinion that the liquid injection practice by now is compliant with the Requirement 18 of [1] therefore no further recommendations are made.

5.2 WASTE ACCEPTANCE CRITERIA

Russian Federation's position

The Waste Acceptance Criteria (WAC) were derived from the results of laboratory studies of interaction of waste with rocks characteristics for disposal site and modified in accordance with operation experience.

WAC concentrations of fissile materials (Pu, U) were derived based on nuclear safety consideration (avoid chain reaction) and to reduce the potential interest in extracting of the injected waste. Thus, nuclear safety assurance in underground disposal of ILW is assured by limitation of concentrations of ^{239}Pu and ^{235}U in the disposed waste. Pu concentration should not exceed 0.25 mg/l.

Heating of the environment and specific heat generation of waste depend on the radionuclide composition and specific activity of waste. Threshold value of specific heat generation of waste was set based on calculation of heat-up of the host geological environment, which should be below phase transition temperatures in reservoir bed conditions at reservoir bed pressures. To study the heat development, between 1970 and 1972 experiments were carried out by injecting HLW.

Limitation on heat generation is 180^{0}C.

Long-lived radionuclides concentration having the highest levels of heat generation taking into account the possible heating of the reservoir bed was limited.

Gas generation at the injection wells is due to radiolysis, direct and reverse radiolytic processes. Another factor causing gas generation is the activity of denitrifying bacteria.

In experimental works, the activities of denitrifying bacteria and generation of molecular nitrogen in the bed had led to complications due to origination of the gaseous lift. Subsequently the process of waste preparation to disposal was changed: nitrate quantity was limited, and there were no more unfavorable events.

Fine-dispersed solid particles concentration is regulated (5 to 100 mg/l). The limitations established for suspended material concentration in liquid radioactive waste resulted in twofold or even higher decline of the hydraulic conductivity factor.

The chemical composition of the waste was derived from the requirement that interaction of waste with the rock of the geologic environment should maximally retard the migration properties of the radionuclides by such processes as oxidizing and ion-exchange sorption, sedimentation, etc.

The "threshold" concentrations for waste components that are supposed to be aggressive towards the reservoir bed rocks (waste may only be low-acid or low-alkali) were established; concentrations of alkalis and acids were taken in accordance with the results of chemical and physical tests performed for samples of reservoir bed rocks.

Waste acceptance criteria for the different waste types are provided (^{137}Cs, ^{90}Sr, alpha-emitters).

WAC on radionuclide content is verified by taking and analyzing liquid radioactive waste samples.

Samples are taken from the surface of intermediate pool prior to feeding the waste for underground disposal; subsequent samples are taken every 0.5 m of pool depths down to pool sediments. Samples are taken at the suction head of the pump. Such a procedure of sampling was selected to eliminate indeterminacies in liquid radioactive waste composition due to variations of salt composition (and, consequently, liquid radioactive waste density) with depth, which is caused, in particular, by ingress of melting and rain waters to the pool. The samples are analyzed against the WAC.

During waste transport from the intermediate reservoir to disposal facility additional samples are taken. Every 10 000 m^3 of disposed LLW: the samples are analyzed for beta-activity, salt content, sodium nitrate, hardness, sulphate, chloride, and bicarbonate ions, hexachloro-butadiene, tributyl-phosphate. Every 20 000 m^3 of disposed LLW: the samples are analyzed against the WAC and additionally to identify beta- and gamma-active nuclides, sum of alpha-emitting nuclides, ^{90}Sr, surface agents, dry residue, fixed residue, density.

Control of observance of WAC is also performed through analysis of samples from intermediate reservoirs prior to disposal and during the disposal process.

One sample from each reservoir is taken 10-15 days before disposal. The samples are analyzed against the WAC, and a decision to dispose the waste or return it to MCC for adjustment is based on analysis results.

During the injection process: one sample at the level of 300 cm, one sample at the level of 70 cm. Samples taken during the injection process are control ones and are analyzed only if the injectivity of wells drops sharply.

Most of the measurements are carried out within the disposal site. If deviations are found, the injection is stopped and the samples are sent to the central facility laboratory for analysis.

PRT observation

Waste acceptance criteria specify a set of limits to be met by wastes (and waste packages) to ensure that the disposal facility remains within the bounds of its safety assessment and operating license. The WAC is driven by the facility safety assessments - most notably, the safety assessments for post-closure and operation. WAC is a formal requirement within the meaning of the IAEA Safety Standards (e.g. requirement 20 of [1]).

The WAC is in place for the liquid injection facilities and the programme for checking the compliance against WAC appears to be logical and systematic. Nevertheless, normally the WAC should undergo several iterations as progress is made with the safety assessment. Some mentions were made about modification of WAC (e.g. nitrate content) but a systematic revision of the WAC since start of operation with regard to the renewed safety assessment was not provided.

Presence of complexion agents in the waste might be of great importance. Criteria of the complexion agents are not given in the documents. Although the potential role of organic complexants, microbiological activity and colloid facilitated transport is mentioned, detailed characterization and corresponding calculations for these scenarios are missing (might be of importance for the long-lived radionuclides).

An important element of the compliance checking and verification of the WAC is the waste characterization program. It has two primary functions:

(1) to provide an initial estimate of waste characteristics as an input to the safety assessment;
(2) to provide assurance that any limits imposed in the WAC are complied with.

The waste characteristics, including radiological, chemical and physical properties, form the fundamental basis of the safety assessment of the disposal facility. A suitable waste characterization programme must be implemented to quantify the relevant waste characteristics, and to ensure that any limits specified in the WAC are met. Safety assessment should be used to help define priorities. Relation of safety case and WAC has not been fully developed in the package of documentation available to the PRT.

Non-radiological hazards (e.g. heavy metals, organic components, toxic components, microbiological components, etc.) and associated criteria were not part of the Terms of Reference and consequently have not been assessed.

One important WAC relates to the fissile material content of the waste to be injected. When fissile materials are present, the waste has to be emplaced in the disposal facility in a configuration that will remain subcritical. This may be achieved by various means. In the Russian practice it is assured by limitation of concentrations of the fissile materials. The PRT considers that this approach represents an acceptable practice.

RECOMMENDATION

- The WAC should be justified on the basis of safety assessments.
- The PRT suggests that further consideration be given to those criteria that were given much less attention so far (heavy metals, organic components, toxic components, microbiological components, the complexion agents).

5.3 MONITORING PROGRAMME

Russian Federation's position

During operation, monitoring activities are required to ensure the conformity of the waste to the requirements (acceptance criteria) and to verify, by sampling of stratum fluids from the reservoir bed and other horizons that the spreading of the plume remains as expected within the allotment area and the reservoir bed. In particular monitoring of piezometric level of buffer horizon aims at detecting any interconnection between the different geological horizons. Dedicated monitoring of the injection mode (temperature and pressure monitoring) is also carried out in order to verify that any perturbation of the rocks in the reservoir bed and aquitards are minimized. More generally, it is mentioned that the main objective of the monitoring programme, in combination with other studies (e.g. calculations), is to prove and contribute to demonstrate the safety of the disposal safety.

The monitoring activities include: the control of the underground water composition of the reservoir bed and other monitored layers, the control of the water table (level) of underground waters in the collecting and monitored beds and the control of the characteristics of physical parameters reflecting the disposal process impact in the wells and on the surface.

The types, frequencies of sampling as well as the analyzed components and analysis methods are regulated by documents of different levels such as Technological regulations, Standards of technological mode (MCC's instruction), System of operation safety standards (List of controlled parameters (GOST 12.1.048-85)), NP-055-04 regulation on "Disposal of radioactive waste. Principles, criteria and general safety requirements".

As example, documents issued for the purpose of the peer review mention in particular that, at SCC facility, monitoring wells were drilled at a distance of 20-25 m from injection wells to check the conditions of reservoir bed using geophysical methods that allowed observation of the process of reservoir bed filling, parameters of its heating, integrity of operational casings of injection wells and quality of operational and overlying horizons separation.On the Severny site, the overall number of observation wells is 122, 75 of these are currently used for monitoring observations and the rest is temporarily preserved.

PRT observation

The PRT note that the monitoring programme is extensively developed and regulated with the aim to carry out efficient surveillance of the operation of the injection process and to verify that the facility is operated safely as defined in the operating rules. This principle is satisfactory but the PRT note that the results of the monitoring program are used to support the idea that, because current observations, after more than 50 years of injection of liquid radioactive waste, don't reveal any unexpected results and the plume remains in the allotment area, the disposal will continue to behave in the far future as it is expected by forecast calculations: "*The dimensions and boundary of the allotment area were defined basing on the requirement that radionuclides in concentration above permissible level will not reach its border for the period of 1000 years. The modern detailed forecast and monitoring data confirm this. […]*". The operator states (Doc A, 299) that no adverse evolution was observed up to now (no waste components outside the DDF) which confirms the isolation of the reservoir.

The PRT considers that these results are positive and probably reflect a globally satisfactory current behavior of the disposal concept. But the PRT is of the opinion that such observation based on monitoring cannot alone be a guaranty that no unexpected behavior could occur in the future. This statement requires a comprehensive safety demonstration, supported by evidences provided by experimental results, modeling results and monitoring data confirming the consistency and reliability of the forecast modeling of the radionuclides behavior for the appropriate timeframe

The PRT also considers that the monitoring programme as presented in the documentation provided for the purpose of the peer review is of interestregarding the operational safety.

RECOMMENDATION

The PRT recommends that the operator specifically explains, through the iterative update of the safety case and safety assessment, how the lessons learnt from the results obtained through in situ experimental works and monitoring processes are used to enhance confidence in the long-term safety.

5.4 INSTITUTIONAL CONTROL

Russian Federation's position

In accordance with the Federal law "On the management of radioactive waste", periodic institutional control shall be provided for the whole period the radioactive waste remains potentially hazardous. No detailed solutions have been developed at this time, but it is considered that most of the observation wells will be closed during the closure phase. The remaining wells will be used during 200-300 years for monitoring purposes (see Section 5.3). The monitoring results will be summarized every 20-50 years and scope of controls will be reduced based on this summary.

New boreholes will be drilled only in case the location is of critical monitoring importance and the existing boreholes has become unusable.

PRT observation

The initial overall approach for siting the DDF, initiated in the 1950's, was to locate and develop the injection disposal facilities in the vicinity of waste production facilities. The PRT notes that such an approach may present assets for minimizing transportation, but major possible drawbacks related to the presence of water resources in the vicinity of the DDF. Regarding this last point, the presence of aquifers and water resources nearby the facility (Severny for example) necessitates to impose a restriction on the use of the aquifers. Achievement of this restriction relies on active surveillance.

The PRT notes that Document B Table 18 suggests that in the case of flow connection between the reservoir bed and the upper buffer layer and aquifers, ingress of radionuclides into the buffer layer could be significant in case of absence of monitoring. Such a statement implies on the one hand that monitoring is maintained on the timeframe during which radioactive pollution could be significant, and on the other hand that detection of such an unexpected evolution and contamination of the different layers and aquifers can lead to propose corrective or mitigating measures to allow the facility to come back into the safe status, or restriction of use of the polluted aquifer.

Concerning the specificity of the injection practice, the possible contamination of aquifers that would be detected by monitoring activities, would give rise to a restriction of use of the natural resource which will only be possible as long as institutional control is efficient.

The PRT notes that the operator (C-31) indicates that the period of potential hazard, initially of 1 000 y is being reconsidered. The timeframe for potential hazard is now extended to 10^6 y because of the presence of long lived intermediate level radionuclides in such quantity that their potential hazard can't be neglected over 1000 years and must be considered on a much more long timeframe (graded approach). Answers to the questions raised by the PRT indicate in particular that "*On the one hand, there are regulatory requirements for monitoring during the period after the closure of the facility, as well as the need to demonstrate safety in order to maintain social awareness of the risks. On the other hand, the initial principles of establishment of the disposal facility, as well as all subsequent activities on injection, monitoring and control demonstrate that there is no real need to take active measures after the facility's closure, as the passive measures provided by the properties of the host environment were proven to be sufficient*". This statement appears to be in contradiction with: "*All measures of monitoring and* *institutional control will be taken, in addition to communication with the population for the whole period the waste remains potentially hazardous*" since the timeframe over which the waste remains potentially hazardous is being reconsidered up to 10^6 y.

According to the above elements related to the need to ensure institutional control to potentially prevent from use of water resources, the PRT considers that such long durations (10^6 years) are not compatible with the principle of maintaining active monitoring and institutional surveillance as active safety principle.

Another important aspect with regard to time frames is the assumed duration of institutional control. The last sentence of paragraph 217 of Document B suggests reliance on institutional controls for warning future generations. This may reflect an undue optimism regarding the sustainability of active institutional controls into the future.

Requirement 5 of [1] on "Passive means for the safety of the disposal facility" suggests a need for a combination of active and passive institutional controls. Concerning requirement 22, [1] states that reliance on institutional control for near surface facilities should not extend beyond a few tens to a few hundreds of years.

RECOMMENDATION

The PRT recommends that since the function of institutional control after closing a DDF site to prevent intrusion is similar to that for near surface facilities, it appears reasonable to use this time frame of a few hundred years and not to extend reliance on the functioning of institutional control beyond that period.[3]

6. CONCLUSION

The PRT has examined the documentation provided by the Russian Federation for the purpose of the peer review. The PRT recognizes that since the beginning of the practice in the 1960's, the Russian Federation has continuously worked at improving the safety of the operating procedure of injection and better understanding the long-term behaviour of the disposal system.

It is noted that the Russian Federation has legally decided in 2011 to implement technologies of solidification and minimization of the volume of liquid radioactive waste, in line with the international practice. This decision is a positive step toward the development of waste management solutions that would comply with the international approach recommended by the Safety Requirements for Disposal of Radioactive waste [1] and the PRT recommends engaging with the development of a disposal concept that follows this approach.

[3]Several nations are cooperatively addressing what can and ought to be done to satisfy this requirement through the Nuclear Energy Agency's Records, Knowledge and Memory (RK&M) Preservation Project, participation in which may be of benefit to planning the closure of the Russian Federation's LRW injection facilities in the near future.

On the basis of the reviewed documentation provided by the Russian Federation and the exchange of views during the meetings, the PRT has no major observation to make regarding way of operating liquid injection as currently performed.

However, the PRT is not in the position at the moment to affirm that the practice of injection of liquid radioactive waste in the Russian Federation provides protection of humans and environment on a timeframe commensurate with the duration of the potential hazard presented by the liquid waste, basing this position on the IAEA safety standards.

The PRT considers that further work on the demonstration of safety should be carried out in order to comply with the requirements of the IAEA Safety Standards. These improvements relate in particular to:

- The understanding of the evolution of the disposal system considering the influence of different features, events and processes on the waste and the geological medium;
- The appropriate demonstration of the efficiency of the closure system;
- The identification and management of uncertainties and the development of a research program to address the remaining uncertainties.

These improvements of the disposal system understanding and the other recommendations made in this report should be used as basis for the development of an integrated safety case including a safety assessment. After an integrated safety case has been developed, which according to the experts and the level of understanding of the practice might be possible within a timeframe of about two years, it should be used as basis for concluding whether the practice of injection of liquid radioactive waste in the Russian Federation provides a sufficient level of protection of people and the environment for a timeframe commensurate with the potential hazard of the waste. Decision about the practice and on potential measures required to ensure long term safety should be made at that stage. This decision should also consider the safety of the overall system for the management of the existing liquid waste and the stage of development of the solidification programme.

APPENDIX 1
TERMS OF REFERENCE

1. Objective of the review

The peer review will provide an independent international evaluation, based on the requirements set out in the IAEA safety standards, of the safety of deep well injection practices for the liquid radioactive waste management in the Russian Federation.

In particular, the evaluation will focus on practices of direct disposal of liquid radioactive waste into the geological strata through deep injection wells.

Review, evaluation and recommendations will be against the relevant IAEA Safety Standards with the combined expertise of the international peer review team.

The peer review will also facilitate the sharing of good practices identified during the peer review and will provide feedback for the development of the international standards and recommendations.

2. Scope

The Russian Federation nuclear programme produces liquid radioactive waste and effluents.

The major fraction of liquid radioactive waste (97%) accumulated at Russian nuclear industry enterprises is the result of the former defence nuclear activity and classified according to the Russian classification system as low-level radioactive waste. This waste is stored into special reservoirs, mainly at the PA Mayak site.

For low and intermediate liquid radioactive waste management the borehole injection in deep geological formations is in use to isolate radioactive components from the environment. This practice is implemented at three different sites of the Russian Federation territory.

High-level liquid radioactive waste was also isolated for experimental purposes in negligible quantities from the environment through the same technology.

In compliance with the Federal law of the Russian Federation “On the Radioactive Waste Management and on the Changes in Some Legislative Acts of the Russian Federation” (Law No. 190-FL, 11.07.2011) the use of additional sites for injection of liquid radioactive waste is prohibited.

The peer review will address the disposal activities related to liquid radioactive waste injection in the Russian Federation and will give a particular attention to the safety basis and justification for the borehole injection disposal practice including assessment of the long-term impacts on the human health and environment. Predisposal activities will also be considered, as appropriate, for the purpose of obtaining and understanding the necessary information on the characteristics of the waste to be injected. The predisposal management of radioactive waste is not in the scope of the peer review.

3. Basis for the review

The peer review process will use broad professional experience and judgment, supported where appropriate with reference to relevant IAEA Safety Standards.

Documentation related to the Russian Federation regulations might be provided for information. Good practices for wider sharing will be identified.

The peer review, including the identification of the key issues and the findings/conclusions, will be based on and informed by reference documentation such as:

— IAEA safety standards and guidance (see Section 8);
— A self-assessment of the safety of deep well injection for the liquid radioactive waste produced by the Russian Federation on the bases of an IAEA questionnaire;
— Relevant information provided by the Russian Federation and as required prior to the peer review and during the review, if necessary. For the purpose of the review, the international peer review team will have the possibility to request additional documentation.

4. Modus operandi

The working language of the mission will be English and when necessary interpretation will be provided by the Russian Federation.

Responsible Russian Federation and IAEA Coordinators will be nominated.

The appointed Russian Federation coordinators will be responsible for:

— being the representatives of the Russian Federation to communicate with the IAEA Coordinator;
— agreeing the Terms of Reference with the IAEA Coordinator;
— providing all of the documentary information to the IAEA Coordinator prior to the peer review and during the missions, if necessary;
— ensuring the appropriate review questions are answered and returned to the IAEA in due time;
— making all of the arrangements within the Russian Federation needed for the activities related to the peer review;
— collating all Russian Federation comments related to the draft review report, specific comments on the usefulness of the safety standards and generic comments on the experience of the peer review; and
— Participating as an Observer to the review meetings organized by the IAEA.

The IAEA Coordinator will be responsible for:

— agreeing the Terms of Reference with the Russian Federation;
— liaising with the Russian Federation through the appointed Coordinators;
— ensuring the IAEA questionnaire provision to the Russian Federation in due time;
— the coordination of all IAEA activities relating to the peer review;
— the establishment of the peer review team;
— ensuring that the peer review team members signed the non-disclosure agreement with the IAEA.

The overall peer review process consists of four phases:

(a) Preparation and initiation - A preparatory meeting between the IAEA and Russian Federation will be held to further clarify: (i) the Terms of Reference; (ii) the scope of service; (iii) the work plan; (iv) appropriate reference documentation;

(b) Initial information - This phase includes the self-assessment exercise according to the questionnaire and the transmission of its result and any other existing information by Russian Federation and its subsequent distribution by the IAEA to the peer review team members for

preliminary evaluation. A copy of relevant IAEA documents for the review will also be distributed to the team.

(c) Review meetings – The purpose of the meetings will be to enable the Russian Federation to give comprehensive presentations of its liquid radioactive waste management practice with the use of deep well injection, and will provide an opportunity for the team members to hold technical discussions on particular issues (e.g. response to issues identified by the team), and discussions with the Russian experts.

The peer review, performed on the basis of the IAEA Safety Standards, will be two stages:

- A pre-mission will take place in December 2012 (see schedule below) during which the experts will perform a preliminary review of the documentation provided by the Russian Federation regarding the safety of the liquid injection practice. This pre-mission will allow in particular identifying any additional information and documentation to be provided by the Russian Federation prior to the final peer review mission.
- The final peer review mission will take place in June 2013 (see schedule below) with the objective to perform the evaluation of safety of the liquid injection practice in the Russian Federation, on the basis of the complementary information and documentation provided.

Ideally, a site visit is planned during the pre-mission in December 2012. However, for practical reasons (authorization access) this visit might not be possible in December 2012 and would consequently be postponed during the final peer review mission in June 2013.

At the end of the final peer review mission the initial draft report of the peer review will be provided to the Russian Federation for facts checking.

(d) Final drafting meeting – A meeting will be held in Vienna by the IAEA and the team of experts in order to prepare the final draft report of the peer review.

5. International peer review team

The IAEA will convene a team of international experts to perform the peer review according to the Terms of Reference agreed upon with the Russian Federation. The team will comprise 5 qualified and recognized international experts and 2 IAEA staff respectively from the Waste and Environmental Safety Section (Department of Nuclear Safety and Security) and the Waste Technology Section (Department of Nuclear Energy) with experience in radioactive waste management and radiation protection. The IAEA will formally consult the Russian Federation regarding the composition of the proposed review team prior to conducting the mission. This consultation only concerns the different disciplines composing the international team, not the individual members of the team.

6. Reporting

The results of the peer review will be documented in a final report that will contain the conclusions of the review team. The report will reflect the collective views of the team members and not necessarily those of their respective organization or Member State or the IAEA.

The outcomes of the peer review will be presented at the first meeting of the Commission on Safety Standards following the final draft meeting.

The distribution of the report is initially restricted to the IAEA, review team members, and the Russian Federation. Any further distribution at this time is at the discretion of the Russian Federation. Ninety days after the final report is issued, it is automatically de-restricted unless the Russian Federation requests otherwise. Under agreement with the Russian Federation the IAEA will publish the peer review report in the interest of transparency.

7. Host Organization documentation for review

The Russian Federation should make any relevant reference material and documentation available to the IAEA sufficiently in advance in English.

This documentation will cover:

(a) documents to be subject of review by the team;

(b) additional documents reviewed and discussed during the missions; and

(c) other relevant national documents that need to be considered.

8. Reference documentation for the review team

The IAEA Safety Standards will serve as the main referential framework for evaluation, in particular the following:

— INTERNATIONAL ATOMIC ENERGY AGENCY, Fundamental Safety Principles, IAEA Safety Standards Series No. SF-1, Vienna, (2006).

— INTERNATIONAL ATOMIC ENERGY AGENCY Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards - Interim Edition General Safety Requirements Part 3, IAEA Safety Standards Series No GSR Part 3, IAEA, Vienna, (2011).

— INTERNATIONAL ATOMIC ENERGY AGENCY Safety Assessment for Facilities and Activities Safety Requirements, IAEA Safety Standards Series No GSR-Part 4, Vienna, (2009).

— INTERNATIONAL ATOMIC ENERGY AGENCY Predisposal management of Radioactive Waste Safety Requirements, IAEA Safety Standards Series No GSR-Part 5, Vienna, (2009).

— INTERNATIONAL ATOMIC ENERGY AGENCY, Disposal of Radioactive Waste Safety Requirements, IAEA Safety Standards Series No SSR-5, IAEA, Vienna (2011).

— INTERNATIONAL ATOMIC ENERGY AGENCY, Classification of Radioactive Waste, IAEA Safety Standards Series No GSG-1, IAEA, Vienna (2009).

— INTERNATIONAL ATOMIC ENERGY AGENCY, The Safety Case and Safety Assessment for the Disposal of Radioactive Waste, Safety Guide (DS 355 in publication – to be published under SSG-23).

— INTERNATIONAL ATOMIC ENERGY AGENCY, The Management System for Facilities and Activities, Safety Standards Series No. GS-R-3, IAEA, Vienna (2006).

— INTERNATIONAL ATOMIC ENERGY AGENCY, The Management System for the Disposal of Radioactive Waste, GSG-3.4, IAEA, Vienna (2008).

9. Funding of the peer review

The peer review activities will be funded by the Russian Federation. The costs for the services (i.e. for meetings and visits associated with providing the peer review) will be limited to the travel costs and per diem of the peer review team (external experts and IAEA staff) and external expert fees in line with IAEA Financial Regulations and Rules.

The costs for interpretation and translation of documents to English will be covered by the Russian Federation.

The costs of official publication of the final report of the peer review (see Section 6 above) will also be covered by the Russian Federation.

The cost of the peer review is currently estimated to the amount of xxx EUR (hereinafter referred to as "the initial voluntary contribution". The Russian Federation is aware that the entire amount of the initial voluntary contribution will need to be transferred to the IAEA's account prior to the initiation of the peer review activities. All reporting dates will be corrected in a case of delay of the initial voluntary contribution. The Russian Federation is aware that the initial voluntary contribution includes 7% programme support costs. If the actual costs of the peer review will exceed the initial voluntary contribution the Russian Federation agrees to cover such additional costs of the IAEA. By transferring of the initial voluntary contribution to the IAEA account. The Russian Federation agrees with these Terms of Reference.

Initial Schedule

	Activity	**responsible party(-ies)**	**Tentative date**
1	Agree on draft of ToR and dates for expert review mission	IAEA, RUSSIA	25th July 2012
2	Finalization of ToR	IAEA	31st July 2012
3	Identify and contact experts, send the potential names of experts to the RUSSIA (for the clearance of the site visit process)	IAEA	3rd August 2012
4	Sending the questionnaire to RUSSIA	IAEA	4th August 2012
5	Letter from DDG to ROSATOM (with invoice)	IAEA	2nd September 2012
6	IAEA receive extra budgetary fund	RUSSIA	1st October 2012
7	Recruit experts	IAEA	1st October 2012
8	Deliver documents for pre-mission	RUSSIA	1st November 2012
9	Sending documents to the experts	IAEA	2nd November 2012
10	Sending questions from the experts to RUSSIA (optional)	IAEA	15stNovember 2012

11	Pre-mission visit	IAEA, RUSSIA	3-7 December 2012
12	Sending the supplementary documents to experts	RUSSIA	15th April, 2013
13	Sending questions from the experts to RUSSIA	IAEA	15th May, 2013
14	Peer review mission	IAEA RUSSIA	3-12 June, 2013
15	1st draft of Review Report	IAEA	12th June, 2013
16	Sending final draft Review Report to RUSSIA	IAEA	12th July, 2013
17	Sending comments on final draft Review Report to IAEA	RUSSIA	30th July, 2013
18	Peer review report	IAEA	14th August, 2013

APPENDIX 2
MEMBERS OF THE INTERNATIONAL PEER REVIEW TEAM

Serres, Ch.	Institut de Radioprotection et de Surete Nucleaire (IRSN), France
Heinonen, J.	Finnish Radiation and Nuclear Safety Authority (STUK), Finland
Goldammer, W.	Consultant, Germany
Kickmaier, W.	MCM McCombie, Chapman, McKinley Consulting, Switzerland
Van Luik, A.	Carlsbad Field Office (CBFO) of the US Department of Energy, USA
Bruno, G.	International Atomic Energy Agency, Team Coordinator
Ormai, P.	International Atomic Energy Agency

APPENDIX 3
DOCUMENTS PROVIDED BY THE RUSSIAN FEDERATION FOR THE PEER REVIEW

- Document A. Liquid radioactive waste deep disposal facilities: history of development and operation;

- Document B. Safety justification of the «Severny» liquid radioactive waste deep disposal facility as the reference one;

- Document C. Concept of safety justification and assurance for liquid radioactive waste deep disposal technology;

- Document D. Lessons learned from the practice of liquid radioactive waste deep disposal;

- Answers to the IAEA questionnaire on geological disposal of radioactive waste;

- Answers to the questions on Documents A, B, C and D for the Peer review on the Deep Well Injection Practice for the Liquid Radioactive Waste in the Russian Federation.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Disposal of Radioactive Waste, IAEA Safety Standards Series No. SSR-5, IAEA, Vienna (2011).

[2] EUROPEAN ATOMIC ENERGY COMMUNITY, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, INTERNATIONAL MARITIME ORGANIZATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS ENVIRONMENT PROGRAMME, WORLD HEALTH ORGANIZATION, Fundamental Safety Principles, IAEA Safety Standards Series No. SF-1, IAEA, Vienna (2006).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Geological Disposal Facilities for Radioactive Waste, IAEA Safety Standards Series No. SSG-14, IAEA, Vienna (2011).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, The Safety Case and Safety Assessment for the Disposal of Radioactive Waste, IAEA Safety Standards Series No. SSG-23, IAEA, Vienna (2012).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, IAEA International Law Series No.1, IAEA, Vienna (2006).

[6] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, ICRP Publication 103, The 2007 Recommendations of the International Commission on Radiological Protection, Oxford University Press (2008).

ANNEX
FEEDBACK FROM THE RUSSIAN FEDERATION FOLLOWING THE REVIEW

The IAEA Peer Review on the Deep Well Injection Practice for Liquid Radioactive Waste in the Russian Federation (hereinafter, Review) was held in 2013 — 2014 in Russia

For both Parties, this extensive Review has provided a unique experience in the evaluation of so called "existing disposal facilities" which were designated, constructed and entered into operation before relevant requirements set forth in SSR-5 "Disposal of Radioactive Waste" were established. Therefore, such facilities may not meet all SSR-5 requirements.

The Russian Federation adheres to the provisions and requirements set down in Section 6 of SSR-5 and puts in place all the required measures to upgrade the safety of these facilities, economic and social factors being taken into account.

In particular, in 2014 — 2015, joint efforts of LRW disposal facilities operator (FSUE "NO RW"), federal body of the state control of the use of atomic energy (the State Corporation "Rosatom") and state regulatory authority on safety of use of atomic energy (Rostechnadzor) provided for the development and approval of a special program enabling to implement the recommendations and remarks of the Review.

In 2015 — 2017, relevant arrangements on its funding from the federal budget of the Russian Federation were implemented.

This program is currently being implemented in Russia engaging not only the operator of LRW disposal facilities (FSUE "NO RW") and different nuclear institutions, but also relevant institutes of the Russian Academy of Sciences (Nuclear Safety Institute, Institute of Physical Chemistry and Electrochemistry, Institute of Global Climate and Ecology). All the efforts are coordinated by Rostechnadzor's technical and support organization Scientific and Engineering Centre for Nuclear and Radiation Safety.

The key outcomes of the efforts performed under this program will be regularly reported in a new Russian specialty magazine "Radioactive Waste". The English version of the magazine will be presented in May 2018 as a side event of the sixth Review Meeting of the Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management.

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