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Report on Task FIN C 1572 of the Finnish Support Programme to IAEA Safeguards

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Abstract

Geological disposal facilities will be developed over a period of at least a few decades. The design and the nuclear licensing of the underground facilities will be generated during the site investigation phase before the regulatory safeguards procedures are applicable. In a geological repository the IAEA will no longer be able to neither to identify nor to re-verify the inventory of nuclear material contained because of the backfilling of the emplacement drifts. Therefore, new geoscientific techniques have been considered for safeguards already before the emplacement of nuclear materials in to the repository.

The examples from the Finnish repository site at Olkiluoto demonstrate that novel evaluation methods and safeguards technologies are to be applied to a geological repository. The safeguards conclusions should be based on integrated analysis of several non-nuclear techniques. The national approach is based on the combination of site inspections and review of construction and monitoring documents. The satellite imagery and seismic monitoring is considered to be most relevant to the international safeguards. However, these records are to be verified timely at the site. The continuous generation of knowledge is to be ensured during the pre-nuclear excavation phase and results documented representing the verified "as-built design information". In order to implement the recommended design information verification procedures by the IAEA and to have granted access to the site and required information, a model arrangement is also presented hereby for further consideration in order to facilitate the IAEA safeguards mission already in the pre-operational phase of the repository.

Contents

1 Introduction

A geological repository is a unique facility type for the perspective of international safeguards because of the long construction and operational periods, the impossible access to emplaced spent fuel that cannot be re-verified and the continuing societal acceptance, environmental safety and safeguards requirement after facility closure. Because of these, different design information generation and verification schedules apply than have typically been used when applying safeguards to surface facilities (IAEA, 1997).

Different methods and techniques shall be used to establish and maintain coherent and reliable picture of the ongoing excavation and operation activities. These includes methods and techniques that enable the safeguards system to provide credible assurances of the absence of diversion of the disposed spent nuclear fuel and of that of undeclared nuclear activities near or at the repository must be ensured during the whole lifetime.

The generic safeguards approach must be applied taking in to account the above conditions and the local geological features, facility concept, excavation and research activities, and the established safety, security and safeguards practices implemented within the existing legal framework. In application particular notice must be taken of the fact that the nuclear fuel elements are not accessible for verification after encapsulation and final disposition of the canisters.

The Finnish Government set the guidelines for the long-term policy of nuclear waste management in Finland in 1983. In particular, the decision was to guide to preparations towards the direct disposal of spent nuclear fuel in a geological repository in case it was not reprocessed. After extensive geological investigations, Finland designated the Olkiluoto area for its national geological repository in May 2001. In addition to the surface and borehole geological investigations, an underground tunnel system is planned to be excavated in the Olkiluoto repository site for the rock characterization purposes during the pre-nuclear phase. These galleries are supposed to form a part of the final repository, in case the investigations confirm this to be the acceptable solution that isolates radioactive materials safely from the biosphere. According to the Decision-in-Principle the solution shall not be harmful to the environment, people and property.

The implementing company, Posiva Oy, was licensed for the excavation of the underground rock characterisation facility as the first stage towards the repository in 2003 by the local municipality of Eurajoki according to the national civil construction legislation. Preliminary works begun in 2003, and the excavations started in 2004. In order to facilitate safeguards, the implementing company provides the authority the required documents, including such as progress reports and planned activities timely. In addition, the main repository drawings and a scientific monitoring programme are also published (Posiva 2003). The information from this geological, hydrogeological and rock mechanical monitoring and research programme to ensure the integrity of the geological repository, including access routes thereto can also be evaluated by the authorities for safety and also for safeguards purposes so that also the necessary safeguards measures can be implemented efficiently, in cost-effective manner.

The regional procedure to generate a traditional Design Information based on Euratom Regulation is not applicable to safeguards yet, because no nuclear material is intended to be transferred into these research premises during the investigation phase of about 6–8 years, nor during the licensed nuclear construction period of another 6–8 years. The operational licensing including emplacement of nuclear materials is scheduled to take place by 2020. The excavation work aiming at the disposal is already declared to the IAEA under the Article 2a(x) of the Protocol Additional as the State's general plan to develop the nuclear fuel cycle. This does not initiate the recommended safeguards activities since the access to the premises for verification routines is not granted implicitly. However, the IAEA was provided with the pertinent information on the excavation plans in 2003. Moreover, the national requirements to generate and verify Design Information as a part of SSAC functions were established in 2004. The proper Design Information and related Basic Technical Characteristics will be provided in accordance with the Safeguards Agreement and in compliance with the appropriate Design Information Questionnaire to be provided by the IAEA.

The Geological Repository Safeguards Experts Group (Member State Support Programme tasks JNT/C1204 and C1226) pointed out that the interface issues between IAEA safeguards and radioactive waste management should be addressed and the use of safety and operational information would make the IAEA safeguards more effective and efficient for geological repository facilities. The Expert Group's report addresses geological repositories during the pre-operational, operational, and post-closure phases. The geological repository and its operations will be monitored during the pre-operational and operational phases, and likely during the post-closure phase, to confirm the assumptions that

1. the repository is operated safely and will effectively isolate the spent fuel from the biosphere, and
2. the contained nuclear materials are not diverted to nuclear explosives or unknown purposes.

Discussions on the site-specific approaches have been initiated, particularly during the Experts Group meetings in Oskarshamn 2002 and in Rauma 2003. The recommendations generated by the group (Okko 2004) focused on the potential information needs and exchange routines. Due to the complexity of the task and verification associated constrains, the need to develop competencies at the IAEA to evaluate and verify geological information to be provided from the repository development project was also indicated. The Finnish Task C 01374 presented the national approach to establish the site-specific safeguards approach (Okko & Rautjärvi 2004).

The recent Integrated Safeguards approach at the IAEA should eventually enable the IAEA to decrease the amount of routine work in its safeguards activities. The aim is to reduce workload at the power reactors in Finland (see Anttila 2000), but construction of a geological repository is not yet addressed appropriately. However, the above recommendations concerning the disposal facility urge to increase safeguards activities from the present 25 annual person-days in Finland remarkably.

This report is concentrated to evaluate the methods used in the comprehensive monitoring programme for the long-term safety evaluations and environmental assessment carried out at the Olkiluoto repository site in order to identify the individual monitoring methods that can be used by the IAEA while developing its safeguards approach for the geological repository in Finland.

2 IAEA safeguards recommendations for geological repositories

The objective of IAEA safeguards is the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection (INFCIRC/153) and to provide credible assurance of the absence of undeclared nuclear materials and activities in a State (INFCIRC/540), in this case in Finland. The IAEA is, on its part, trusted to ensure the application of all measures available to it and, in cooperation with Finland, to implement the respective functions so as to meet the safeguards objectives.

In comparison to above-ground facilities, at which the IAEA has experience verifying design information and implementing safeguards monitoring and verification measures, sub-surface geological repository safeguards present also challenges of unique quality. First, the space, into which the repository will be constructed, is not directly accessible and cannot be directly observed. This implies that methods and techniques not normally used for safeguards must be used for the assurances of the absence of undeclared structures and activities. Second, once canisters are emplaced, the IAEA will no longer be able to neither to identify nor to re-verify the inventory of nuclear material contained in the repository because of the backfilling of the emplacement drifts.

Geological disposal facilities will be developed over a period of at least a few decades. Key decisions, e.g. on the disposal concept, site selection, design, construction in different phases, operational management and closure, are expected to be made in a series of steps. Decisions will be made based on the information generated and thus made available to the key actors at each step and on the confidence that can be placed in that information. The step–by–step approach also offers opportunities for independent technical reviews, regulatory reviews, and political and public involvement. During the pre-nuclear phase, and later during the construction of a licensed nuclear facility, emplacement of containers and operation and at closure, the understanding must be sufficient to support the establishment and implementation of the necessary safety and safeguards regulatory requirements.

In 1988, the IAEA held its first Advisory Group meeting to address safeguards for the final disposal of spent fuel in geological repositories. The IAEA's Programme for the Development of Safeguards Approaches for the Final Disposal of Spent Fuel in Geological Repositories (SAGOR) was begun in 1994 and, in 1998, provided recommendations to the IAEA on generic safeguards approaches for spent fuel conditioning facilities and for operating and closed geological repositories.

The following is considered applicable:

a. Safeguards system shall be based on: establishment and verification of the initial information of the rock volume aimed at accommodating the repository and the essential services; generation of design information during excavations, construction and installation and operation of the repository as well as verification of receipts into and flow within the repository; other pertinent information relating to measures aimed at ensuring that no nuclear material can be removed without notice by any declared or undeclared access routes; and maintenance of continuity of knowledge on the excavated premises and on the nuclear material content.
b. Safeguards requirements shall be integrated into the repository design already at a non-nuclear construction stage in order to establish functional, non-intrusive, and cost-effective safe-

guards measures. Consultations between the State and the IAEA should, therefore, start at that stage to agree on the safeguards measures in the repository.

c. State shall provide the Agency with the pertinent information such as general plans of a geological repository site; description of intended underground works, and any other information such as excavation plans, progress reports and notifications that are identified by the IAEA as relevant for the purpose of safeguards.
d. The Agency, in collaboration with the State, shall establish all pertinent information about the original undisturbed site preferably before excavation begins, in order to establish initial knowledgebase that will enable parties to ensure cost-effectiveness in planning for safeguards approach and in application of respective measures and in establishment of implementation practices.
e. After the repository has been back-filled and sealed the geological repositories is subject to, environmental monitoring and societal controls as will be deemed necessary at that time and that for as long as the safeguards agreement remains in force. The safeguards applied should provide a credible assurance of non-diversion during the whole life time of the repository.

Monitoring will be required during each step or phase of disposal facility development. Purposes include provision of baseline information for site understanding, assurance of operational safety and assessment of repository performance, and measurements to confirm conditions consistent with present and long-term safety and safeguards requirements. These relate to relevant geological site, excavated ramps and other premises, shafts and tunnels, drainages, material and waste handling and other equipment, and radiological control. Monitoring programmes must be designed and implemented so as not to impair the safety in operation and the overall level of long term safety.

In 1998, the IAEA established the Geological Repository Safeguards Experts Group to provide advice on safeguards technology development for geological repositories and on implementing the generic safeguards approach at specific facilities. The pre-operational phase is defined to be the period from designation, by a State, of a site for construction of a geological repository for spent fuel disposal up through receipt of the first disposal container. The safeguards measures are proposed in the report of the Geological Repository Safeguards Experts Group (IAEA, 2003).

The application and practical implementation of recommended measures and techniques need to be discussed and negotiated between the IAEA and the Member State owing to the nature of the challenges and the fact that there are within the IAEA safeguards system no applicable guidelines, for example in the form of design information questionnaires (DIQ), available yet. Also no experience in implementing the IAEA safeguards system during the pre-nuclear phase of the repository development exists.

3 Monitoring methods and procedures for the Olkiluoto site

3.1 Model repository approach

The primary safeguards objective is to ensure that no diversion or reprocessing of nuclear material takes place undetected from the time the material arrives in the repository until the closure and sealing of the repository facilities. The generic safeguards approaches for operating and closed deep geological repositories were defined in the IAEA (1997) report for a model repository. These safeguards approaches were defined more in detail by the experts' group meeting in 2002 (IAEA, 2003). The safeguards system requirements are based primarily on the need to establish initial knowledgebase and to maintain 'continuity of knowledge' (CoK) on the design of the repository and on nuclear material accountancy. The recommended safeguards approach will be to use item accounting supported by a reliable and comprehensive containment and surveillance (C/S) system above ground to verify, inter alia, the transfer and flow of spent fuel containers. Design information verification (DIV) is the recommended primary safeguards measure in the underground areas of the facility. DIV in this instance could include geophysical techniques.

The safeguards approach will depend on the adopted disposal concept (e.g., immediate backfilling or repository kept open until final closure). Because of the undesirability of returning and opening a canister containing irradiated nuclear materials and the inaccessibility of emplaced canisters for verification of any description (either canister identification or radiological inventory), a very high degree of reliability is needed in the safeguards system. This will be achieved by the use of intrinsically reliable systems with multiple redundancies. The safeguards approach may be described as follows. The containment and surveillance system at repository openings may be an integrated system of motion and radiation detectors, optical surveillance and safeguards seals. These will be designed for independent operation and with the ability to provide remote monitoring/analysis of authenticated signals. These systems may reduce the presence of inspectors on the site. The intention will be to provide the inspection authority with a high level of assurance that filled casks received at the surface of the repository are transferred underground to the emplacement vaults without tampering or diversion. All potential access points to the repository would be rigorously monitored to ensure that no undeclared items leave or enter the underground facilities. The instrumental monitoring result will be subject to evaluation in order to be able to launce timely and effective response in case of detection of an event of concern.

Design information verification would be periodically implemented to provide assurance that the physical structure and operations of the repository were consistent with the plans and programme of activities supplied by the State authority to the inspection authority. If necessary, geophysical techniques might be employed as a means of supporting DIV activities as well as optical surveillance. Additional safeguards measures are possible depending on the actual design of the facility (IAEA 1997).

The IAEA Expert Group visited in Olkiluoto the existing and operating underground repositories as well the site selected for the repository of spent fuel in 2003. The Group formulated a set of recommendations how to proceed with the development of possible safeguards approaches (Okko 2004). The suitability of the proposed geophysical methods, environmental sampling, and satellite and aerial surveillance techniques was discussed with respect to the natural conditions of the Olkiluoto area. The inspection regime and timely evaluation process should be by the key elements of the approach to be established.

3.2 Remote safeguards monitoring

The access tunnel to the Olkiluoto repository, called Onkalo during the pre-nuclear phase, will advance 20–25 m in a week, and 1 km in a year. The duration of the excavation of the Onkalo will thus be 6–7 years. After the pre-nuclear period, the repository will consists of the access tunnel, shafts and investigation level galleries (Figure 1). In addition, the underground construction needs supporting infrastructure to be developed at the site. The excavation of a tunnel will introduce environmental effects that may be detected indirect using satellite imagery, airborne methods or geophysical monitoring techniques.

The baseline of natural conditions was reported (Posiva 2003) before the underground operations began at the repository in 2004. Moreover, remote sensing methods were applied for safeguards dem-

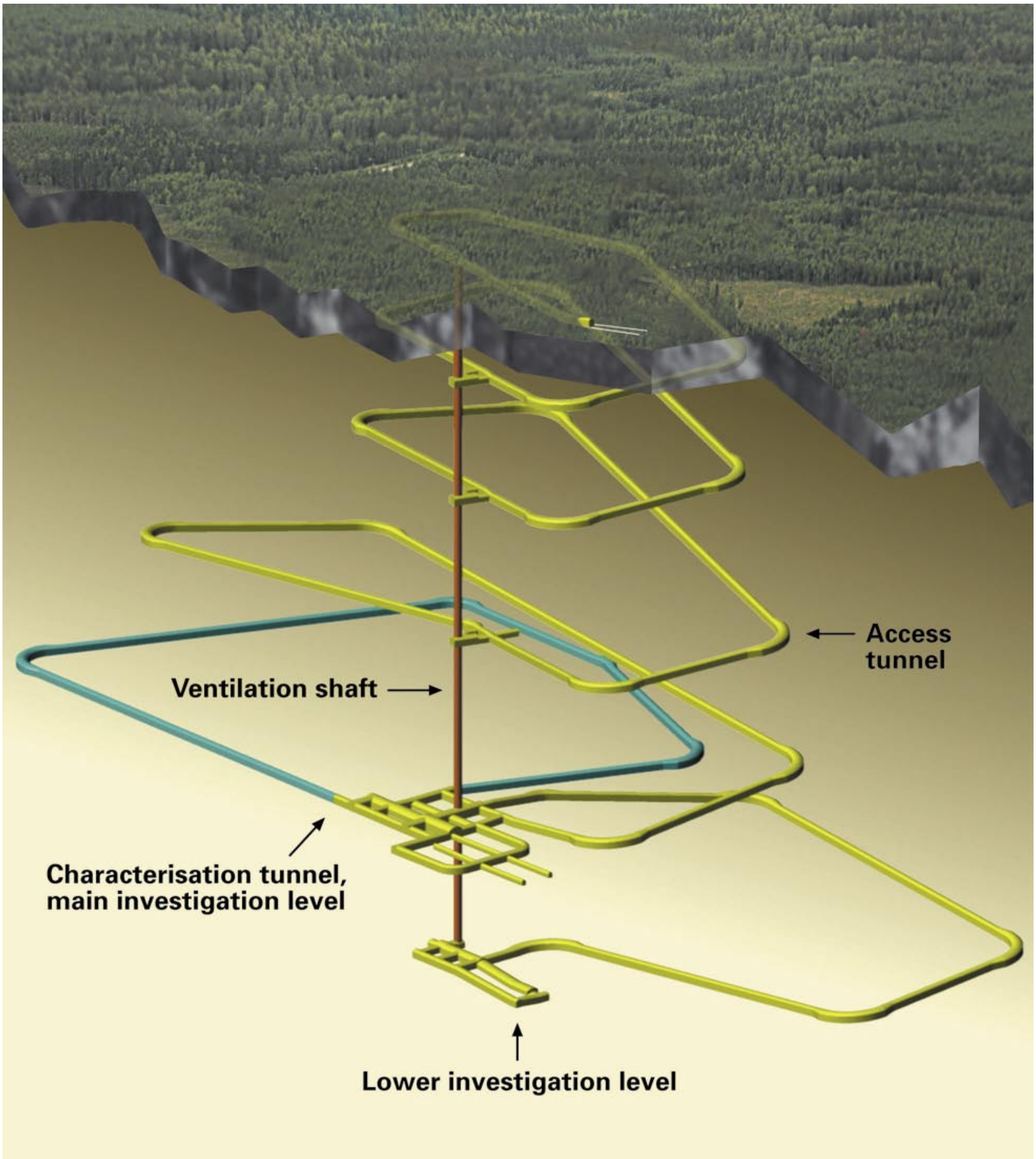

Figure 1. The schematic underground rock characterization laboratory Onkalo to be excavated at Olkiluoto. The disposal tunnels may be constructed from the characterisation tunnel. (Posiva Oy, 2003).

onstrations in the pre-excavation phase (Okko, 2003). At present, the Olkiluoto Island is an active area since there several construction projects going on. The satellite imagery of 2002 was repeated in 2005 and an image comparison procedure was applied to find out changes between the imageries. The changes are illuminated using red colour in Figure 2.

Before the construction of the Onkalo exploratory gallery was initiated, the bedrock remained undisturbed except for the boreholes used for initial site characterization. The removal of vegetation and soils as well as the construction of several civil and nuclear buildings, roads and other objects can be located in Figure 2. The new reactor is constructed on the left near the existing facilities; whereas the repository is constructed near the small reservoir seen on the right. In particular, a land or rock fill

Changes detected between 2002 and 2005 imageries are shown using red colour on the 2005 image.

Olkiluoto area on 9.9.2002

Olkiluoto area on 16.6.2005

Figure 2. Satellite imagery detects major construction-induced changes on surface at Olkiluoto. The landfill area in the middle contains extracted rock masses from several construction activities. The repository site is on the right, near the small reservoir.

area is emerged in the middle of the Olkiluoto Island. However, the rock masses excavated at several locations cannot be located for their origins. There are also newly constructed surface connections between the repository area and the declared nuclear facilities as well as connections to "undeclared" civil buildings. The rock masses extracted and stored on the surface could correspond to a 2…3-km long tunnel network underground – depending on the tunnel dimensions. Therefore, the existence and locations of these tunnels can only be verified in situ at the site. On June 16, 2005 the tunnel length in the repository exceeded to 500 m; whereas, most of those rock masses originated from foundation works at other locations. Although the safety requirements for the nuclear waste management require that the disposal site will be an isolated one, the IAEA safeguards presence at the site is essential and desired for the international confidence building on the absence of clandestine underground operations.

3.3 Monitoring for safety assessment and environment

The characterisation programme is carried out to update and increase confidence in the descriptive model of Olkiluoto bedrock in such a manner to that it will serve the needs of the preliminary safety assessment report required in the construction licence application. During the characterisation programme new techniques to characterise volumes of rock from the underground will be developed and demonstrated. Moreover, the rock volumes that could be suitable for housing the final repository will be identified. The characterisation programme will be followed continuously and reviewed in 3 year intervals by the national authority. The reviews will also focus on the safeguards relevance of the observations.

The underground construction will affect the surrounding rock mass and the groundwater flow system. The expected hydraulic disturbances are simulated by Löfman & Meszaros (2005). In case the tunnels will be left open without grouting strong inflow of water may cause a sink of 200 m in the water table. Also the upconing of deep saline water can be expected. Tight grouting can reduce the depression of ground water table to 10 m. The changes in rock stresses including the tectonic movements in the land uplift zone of Finland are expected to introduce microseismic and seismic events.

The progress in the excavation work and the responses in the monitoring programme is followed and evaluated by an international regulatory expert group which support the safety-case evaluation. These evaluations (e.g. Cosgrove et al. 2003) discuss the uncertainty analysis of the geological data, but can also be studied to support the safeguards approach at the site. The IAEA can be recommended to join the evaluation work in order establish the recommended expertise to generate site understanding at the Agency in the non-intrusive manner as applicable.

The information collected for characterisation and monitoring by independent qualified subcontractors will be assessed in an integrated modelling. The aim of this modelling is both to successively enhance the description and understanding of the rock volume around Onkalo and to assess potential impacts of the construction and operation of Onkalo (Posiva 2003). Integration between monitoring and modelling in different scientific disciplines, including safeguards aspects, is essential during the development of the Onkalo.

The monitoring programme for site understanding and long-term safety is subdivided into

- Rock mechanics
- Hydrology and hydrogeology
- Geochemistry
- Other disturbances

The environmental monitoring programme is subdivided into

- Landscape properties
- Input for biosphere modelling
- Input to environmental impact evaluations

The rock mechanics monitoring includes; i.a., displacement measurements at tunnel walls, stress measurements including loads in rock bolts, analysis excavation damaged zone. The tectonic movements are monitored at the surface by precise levelling, GPS-surveying and seismic monitoring. Rock temperature monitoring is including in the rock mechanical part of the programme.

The extensive hydrological monitoring programme will continue and focus on in flow rate in the tunnels, changes induced in hydraulic heads and evaluation of the hydraulic network. The saline water interface will be monitored using geophysical wireline logging and groundwater sampling in deep boreholes. Geophysical resistivity and electromagnetic monitoring are planned at certain locations to map changes in the conductivity structure of the rock mass. Most of the monitoring data are collected in measuring campaign for hydraulic heads, groundwater flow and hydraulic conductivity. The campaigns are carried out weekly and automatic motoring devices may be involved in the data collection procedures.

The geochemical monitoring programme will continue to analyse the ground water chemistry in boreholes. In addition, the in flow to the tunnels will be analyses for the water chemistry. The effects of cementation and organic materials and the movements of redox front are of particular interest. These topics require calculations with geochemical modelling codes. Equilibrium and mass balance approaches are basic tools in understanding processes like mixing, pH-Eh evolutions and salinity distribution. Furthermore, long-term evolution and predictive problems related to hydrochemical evolution requires coupling of hydrogeological and geochemical modelling approaches.

Environmental monitoring data are used in evaluating the environmental impact of the progress in underground works. The biosphere modelling is focused to analyse the drainage areas, terrestrial, limnic and marine/brackish systems and will make use of the environmental programme operated by the adjacent nuclear power plant. The environmental data collection supports also the hydrogeological analysis of the repository site. In addition, the inventories for terrestrial animals and vegetation are updated annually.

The monitoring programme is reported annual for its individual disciplines (Rock Mechanics by Riikonen 2005, Hydrology by Ahokas et. al 2005, Geochemistry by Hirvonen 2005, Foreign Materials by Juhola 2005, Environment by Haapanen 2005), annually, e.g. Posiva Working Reports 2005-27 … 2005-31. During the first excavation year the disturbances have been minimal, even smaller as expected. There rock quality has required almost continuous grouting around the tunnel which has reduced the inflow water more than assumed in the modelling work.

In order to make an access to the repository, the crystalline bedrock must be blasted; maybe a large coring machine could be applied for tunnelling. These activities introduce noise and vibrations that might be detectable. The removed rock mass must also be stored or hided somewhere. The mass transfer will introduce activities that can be detected. Moreover, the maintenance of a tunnel needs electricity for drainage and ventilation, which requires installations that are detectable. Also the consequences of a tunnel would be observed the hydrological monitoring of the repository. The most advanced and systematically applied site investigation methods are described by Öhberg 2006). These methods are listed in Appendix 1 in which these are also evaluated for their safeguards-relevance. The most promising methods are the continuous seismic and hydraulic monitoring systems to obtain indications on unexpected events. The environmental analysis of the monitoring data can also support the safeguards objectives, but inconclusiveness may retain in these analysis.

There are several geophysical techniques used in the monitoring that are applicable to detects voids and openings within the bedrock, although the possible existence of a clandestine tunnel at the repository site of Olkiluoto is difficult to prove. However, the effectiveness of geophysics, mainly active seismic or electromagnetic methods depends on the size and distance of the object. Also the physical parameters between the void (water, air) and the host rock affect the detection ability. The sounding frequency and other operator-dependent sounding parameters should also be defined according to the (unknown) target. These methods are applied to map the water-bearing or filled fractures in the bedrock. It can be assumed that the number geophysical anomalies interpreted to originate from unknown bedrock features between known boreholes is rather high. Therefore, the direct mapping of unexpected tunnels beyond the reinforced tunnel wall using geophysical techniques in the repository may generate fuzzy information also in the geological bedrock modelling. The origins of all of anomalies can not be verified without extensive drilling and coring (see e.g. Saksa et al. 2005). The applicability of geophysical methods in cost-effective safeguards is not very obvious.

4 National safeguards measures at Olkiluoto repository site

The national system of Finland is implementing the necessary safeguards measures, carrying out the respective functions, creating the knowledgebase and maintaining of the continuity of that knowledge for the generations to follow and during the whole lifetime of the repository. The reporting of the progress in the construction of the underground repository is incorporated to the strengthened national SSAC-functions, thus enabling also the IAEA to apply its respective safeguards measures.

The Finnish national safeguards system for the repository consist of generation of relevant data and information, field audits and verifications as well as review of the progress in tunnelling works and site characterisation. The safeguards-related audits and verifications will be also focused on the contracted companies and their procedures. The national competent authority STUK will, in addition, use information from independent surveillance or monitoring techniques. The national system functions are implemented in such a manner that the IAEA efficient and cost-effective safeguards for the Olkiluoto repository site are enabled.

4.1 Underground design information

The design information generation and verification for safeguards purposes is incorporated to the progress in tunnelling and to the geological mapping of the tunnel walls. The tunnels and the shaft will be reinforced by bolts, sprayed concrete, grouting and possibly also steel mesh or cast concrete structure reinforcements according to the results of rock mechanical investigations. In order to limit groundwater ingress the tunnels will be pre-grouted and post-grouted according to the results of rock mechanical investigations. The methods and the amount of reinforcement and grouting will depend on local conditions, and may thus change even within short distances along the tunnel wall. This requires coordinated investigation, design, construction and inspection activities to recognise the most suitable solutions in advance, and to handle possible unexpected changes in the layout of the Onkalo.

The excavation procedure requires the generation of rock spaces for the drilling, blasting, loading and transport vehicles to pass each other. These spaces are of the order of the volume needed for the treatment of a spent fuel transport canister. Therefore, it is essential to map and verify these spaces and corresponding virgin rock walls after the excavation (see Figure 3). These spaces can be left as open volumes or used for other construction, research, maintenance or safety functions.

The verification of the progress in tunnelling is carried out in such a manner that the excavated volume can be documented in concordance with the geological investigations before the rock walls are reinforced. After the reinforcement, the existence of any undeclared voids is very difficult to prove without disturbing the operational safety of the underground gallery and later, that of the facility. The excavated rock spaces are declared by the operator timely, as shown in Figure 3. The reinforced tunnel sections are documented separately once a decision for the use of spray concrete etc. for operational safety reasons is made. The tunnel sections are inspected by the national safeguards and safety authority before each of the scheduled casting campaigns. The impregnate rock walls will form the repository containment in which the facility installations can be constructed safely. The containment features of the excavated rock space are identified, authenticated and documented, thus providing the basis for license application and the Design Information at the given time in the future.

The measurement of the excavated rock spaced is carried by traditional surveying techniques as well as by laser scanning, which gives for analytical and documentary purposes a detailed 3-D space representation of the tunnel surface. Repeated surveys will be analysed as quantitative displacement measures of the safety analysis. The documentation will be complemented also by visual observations, photography etc. needed for the geological characterisation of features at rock walls. The resolution of any of these methods is considered satisfactory for safeguards purposes. The authenticity and relevance of the documentation is ensured by in-situ presence of inspectors. The national system functions include visual in-situ verification documents to be maintained for the continuity of knowledge. During the first year of excavation works, the national authority carried out in total 14 inspections at the site, 9 of these were documented also for their safeguards-relevancy. There is access to the underground repository during the monthly follow-up meetings and during the international evaluation of the site characterisation and monitoring programme. Safeguards inspections are carried out on ad hoc principle or before the announced casting campaigns.

4.2 Geophysical monitoring

A wide range of geophysical techniques is applied to generate raw data for the site characterisation of Olkiluoto. The data will be interpreted for the geological characterisation of the bedrock and especially for the location and characterisation of zones of mechanical or hydrological interest in the safety assessment. These interpretations will also be reviewed for their safeguards-relevancy. The rock mechanical monitoring is considered to will give the most safeguards-relevant information. Therefore, the microseismic data included in the rock mechanics part (Saari 2005) is applied as safeguards-relevant declaration by the operator (Figure 4). The excavation-introduced seismicity will also be studied using a net work of microseismic stations at the investigation site. These seismic records are then inversed to estimate their source locations in the bedrock volume. The blasting, i.e., the explosions shot to proceed with the tunnels are also recorded with this seismic network operated by the subcontractor of the implementer, Posiva

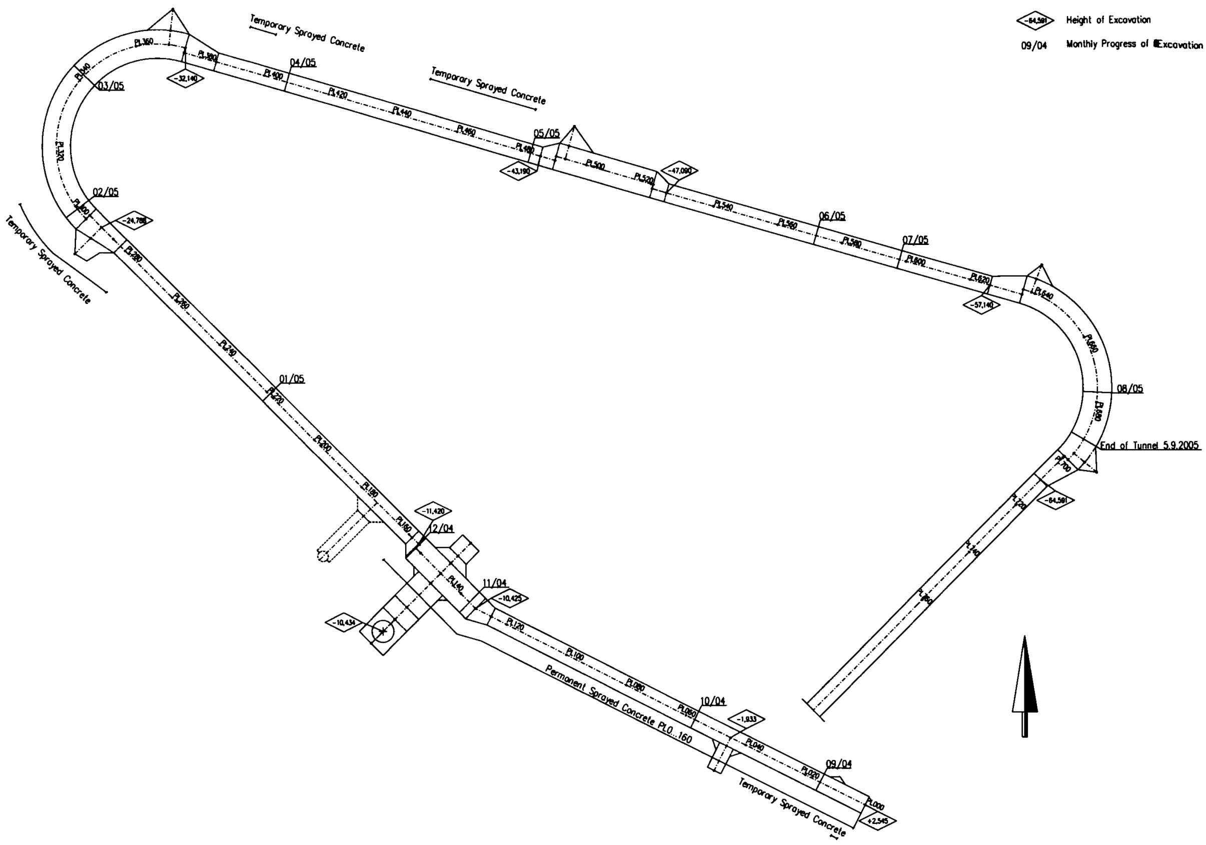

Figure 3. The "as built design information" of the Onkalo ramp at the scale to be verified for safeguards purposes.

Oy. The interpretations are also reviewed by the national authority, STUK.

The microseismic records are analysed for the source locations of the explosions. An example is presented in Figure 4 which shows explosions both from "declared" and "undeclared" activities. Most of the "undeclared" activities can be traced to locations where authorised construction actives are taking place. The seismic analysis can be compared with the satellite imagery of Figure 4. In the seismic data set two clusters are to be identified: the progress in tunnelling work at the repository and the foundation work at the "undeclared" visitors' centre. Excavation work at the reactor site consists of separate working areas or the microseismic network/algorithm tracing the source location is not adequate for this source area. In addition there are several other seismic events that cannot be identified exactly. It is obvious that these are individually related to vibrations at landfill areas and near roads, and thus having no safeguards relevancy. However, the main conclusion from these seismic records is that it is confirmed that there are no underground connections made (during the monitoring period) between the construction sites observed in the satellite imagery.

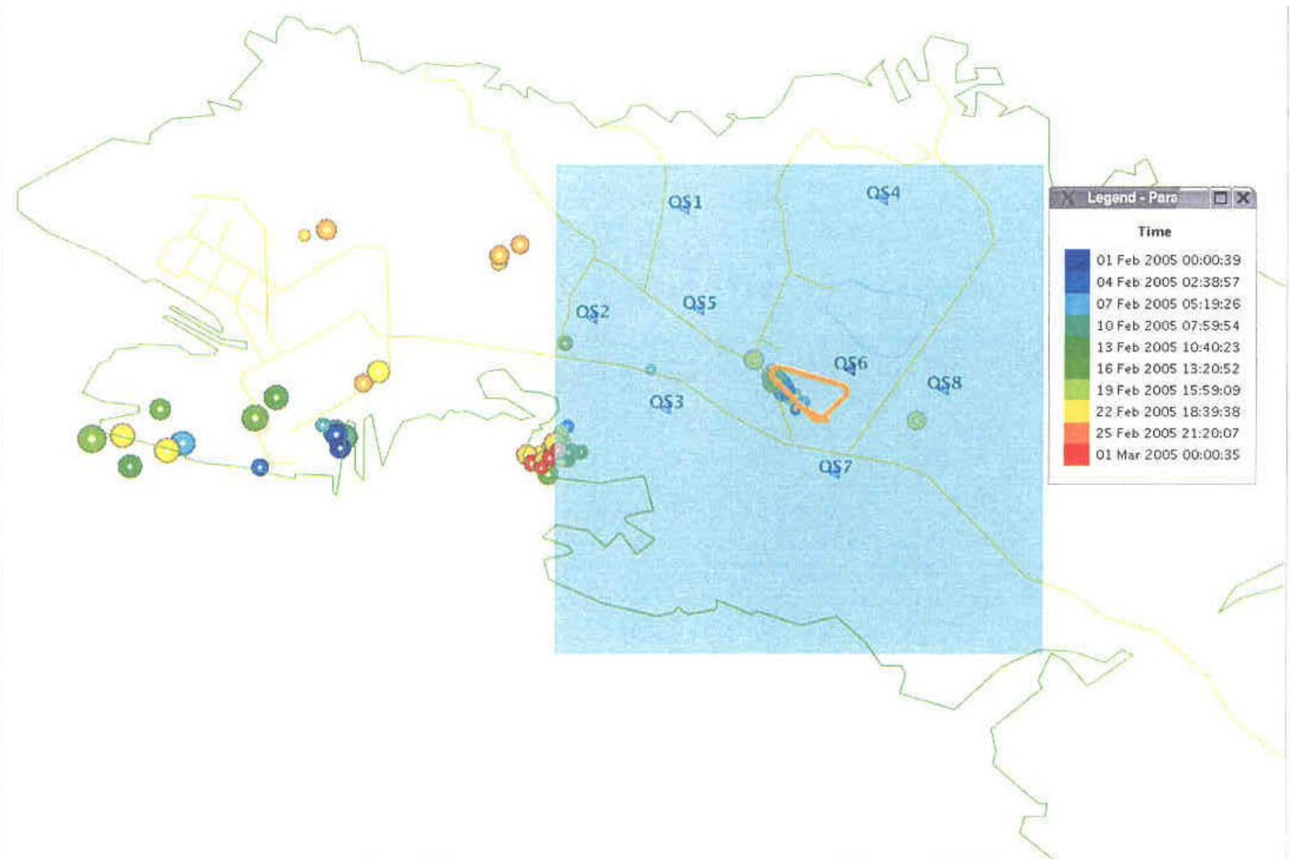

Figure 4. Seismic epicentres as traced their source location in February 2005. The Onkalo ramp in marked by the orange triangle and the repository area is dashed bluish.

5 Recommendations to the IAEA safeguards at the Olkiluoto repository

The model repository approach would require practically continuous human and instrumental presence at the site during the whole life time of the repository. The maintenance of the IAEA monitoring equipment would require also technical people to be reached at short notice. Assuming that there are at the IAEA inspectors who are competent to carry out the continuous design information verification and geo-scientific monitoring and evaluation, it is estimated that at least 1.5 – 2.0 person-years are needed annually at the site in the pre-operational phase of the repository. In addition, there is an obvious need for geo-scientific staff at the head quarters. This increases the inspection activities remarkable from the present 1 person-month spent annually in Finland, in contrast to the Integrated Safeguards aim to reduce the inspection activities.

The IAEA is recommended to make full use of Finnish national safeguards system, its findings and the existing technical possibilities so as to ensure cost-effectiveness of its safeguards and also to avoid unnecessary burden on the operator and the national system. In particular, its approach to safeguarding the pre-nuclear phase of the repository construction should include the following:

1) Audit of the national system elements and their safeguards functions.

2) Examine progress reports and the as-build design information.

3) Assess the findings of the national monitoring system so as to be assured of the absence of undeclared activities, structures, equipment and materials considered to be of safeguards relevance.

4) Access on short notice the enabling national system elements and, as required by the IAEA system, also the geographical site, buildings, equipment and excavated premises to verify in-situ (by use of proven methods) the correspondence with the progress reports and as-build design information.

5) Approach the national system in case of anomalies, inconsistencies or questions of relevance for safeguards so as to obtain required clarifications.

The cost-effectiveness in implementation of the IAEA safeguards measures could be based on the short notice random visits to the repository and periodic follow-up of the site characterisation and monitoring programme performance. The visits and adjoining verification activities applying mainly visual observations or surveying techniques might be carried out in concordance to routine inspections to the near-by located nuclear facilities to avoid travel costs or in an unannounced mode.

The monitoring programme performance and results are followed by the scientific expert group that also inspects quality and safety assessment of the repository annually. The participation in this group might be the most convenient and cost-effective way to maintain the required level of site understanding, thereby contributing to the safeguards evaluation. This procedure that could include the as-built design verification would require few person-days annually and would include assessment of the monitoring programme results and performance from the safeguards relevant points of view.

In general, the information needs and exchange routines are to be defined, since there are no legally binding obligations, neither in the Safeguards Agreement nor in the Additional Protocol guiding the State and the IAEA in the implementation of safeguards on geological repository in the pre-nuclear phase. The pre-nuclear phase should be declared as a general plan to the development of nuclear fuel cycle. In addition, the notification, reporting and other communication formalities as well as access procedures have to be negotiated and agreed with the relevant parties. A draft arrangement that takes into account Olkiluoto site specific aspects and the existing national safeguards system elements is presented in Appendix 2.

6 Conclusions

The final disposal of spent nuclear fuel in the geological repository at Olkiluoto was accepted be the local municipality, State authorities, and finally endorsed by the Parliament of Finland in 2001. The site investigations proceeded to the underground phase in 2004 when the excavation of the underground tunnel system for bedrock characterisation at repository site began. Referring to the recommendations generated in the International Atomic Energy Agency's Programme for Development of Safeguards for Final Disposal of Spent Fuel in Geological Repositories, the implementation of the necessary safeguards measures by the national safeguards authority was initiated in 2004. The IAEA is recommended to make full use of this strengthened national system.

The main safeguards objectives at the present pre-nuclear phase are: 1) Generation and verification of the as-build design data that corresponds with the excavated rock space and its geometrical volume 2) Assessment of all available safeguards relevant monitoring data to assure the absence of undeclared safeguards-relevant activities at or near the repository.

The extensive geo-environmental monitoring data collected continuously primarily for site understanding and safety evaluation purposes are also accessible, as relevant, for the safeguards purposes. Integrated evaluation of the information generated by these monitoring tools can reveal indications concerning undeclared activities near or at the repository, thus providing a set of data and information that can contribute to the required assurances of the absence of undeclared activities and man-made structures of safeguards relevance.

In general, the monitoring methods contribute to the establishment and maintenance of a coherent and reliable set of data and information for the use in drawing safeguards conclusions at the geological repository site. These methods are, however, insensitive to the amount of rock volume excavated or to the volume and shape the underground space produced. Therefore these can not be used for design information verification, namely to establish correspondence between the declared excavated rock volume and its declared shape and the one actually constructed.

Taking into account the complexity and novelty of the subject matter availability of appropriate non-nuclear safeguards competencies must be secured at the inspectorates. It is recommended that the IAEA and the relevant other parties in Finland will negotiate legally binding implementation arrangements so as to ensure that the national system functions will be implemented through out the whole lifetime of the repository project in a manner that enables the IAEA to implement its safeguards obligations in Finland effectively.

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APPENDIX 1 Investigation methods applied at the Olkiluoto site

(Öhberg, 2006)

Method	Application	Data obtained	Safeguards-relevance	Safeguards-applicability
Hydrology	**in boreholes**	**timely obtained point-like samples**	**interpreted results, no direct sg-conclusions can be drawn**	**Increases site understanding, indications on undeclared activities may be obtained**
	Flow logging	Hydraulic (continuous) profiles along borehole		
	Hydraulic testing	Point-like hydraulic data		
	Water loss tests	Permeability near the borehole		
	Multi-packer monitoring	Continuous data on hydraulic heads		
	Pressurised water sampling	Chemical water samples		
Geophysics	**on ground surface**	**Spatial data, interpreted subsurface points/profiles**	**Limited penetration/ resolution in repository, no direct sg-conclusions can be drawn**	**Increases site understanding, indications on undeclared activities may be obtained**
	Slingram survey	resistivity-depth points/ profiles		
	Refraction survey	interpreted seismic cross-section		
	Resistivity sounding	resistivity-depth points/ profiles		
	EM (Gefinix 400S) sounding	resistivity-depth points/ profiles		
	Ground penetrating radar	interpreted cross-section		
	Charged potential	interpreted cross-section		
Geophysics	**in boreholes**	**Interpreted profiles along and around boreholes**	**Advanced penetration/ resolution, no direct sg-conclusion can be drawn**	**Increases site understanding, indications on undeclared activities may be obtained**
	Geophysical logging	Interpreted profiles		
	Optical televiewer	Visualised profile		
	Borehole radar	Cross-section near-by the borehole		
	Seismic crosshole	Cross-section between boreholes		
	Seismic VSP	Imaged reflectors in the rock mass		
Rock mechanics	**on ground and in the subsurface**	**Direct or interpreted point-like data**	**Direct measurements of rock stability, may be analysed for sg-purposes**	**Increases site understanding, indications on undeclared activities may be obtained**
	GPS network	Timely point data on ground movements		
	Precise levelling	Timely point-data on vertical movements		
	Seismic monitoring	Continuous point data on epicentres		
	3D-laser scanning	Timely point data on tunnel walls		
	Rock stress measurements	Timely point data in boreholes		

APPENDIX 2 Model Arrangement to facilitate the IAEA Safeguards in the pre-nuclear phase of a repository

MODEL

Safeguards Arrangements between State and the IAEA during the excavation of "Rock Characterization Facility" associated with the Geological Repository of Spent Fuel

1. Preambular

The general guiding values identified hereby are aimed at ensuring that effective safeguards can be implemented at the time the underground installation is forming a part of the licensed nuclear facility under construction.

During the pre-nuclear excavation phase particular care will be taken, that

- Measured geometry and volume of extracted rock correspond to the actual size and structure;
- Respective data and information are generated, documented, made timely available for verification by the relevant parties;
- Periodic as-build-design information verification is carried out in accordance with the agreed practices, and that
- Assurances will be there of the absence of any undeclared underground activities and structures of safeguards relevance.

The nature of continuing underground excavation work with blasting activities requires that specific safety and security provisions in force must be respected by all parties. Therefore advance notification procedures shall complied with so that the operational safety requirements can be adhered to and non-intrusive inspection and monitoring activities facilitated. *The following principal considerations are important in ensuring safe and timely access as well as efficiency in the implementation of the required safeguards measures:*

- The frequency and intensity of activities described in this Arrangement shall be kept to the minimum consistent with the objective of efficient safeguards.
- The operator needs to be informed at least one week in advance of a need to carry out routine activities in the underground premises.
- The advance notification shall be in writing and shall specify the reasons of access, identify the designated inspectors, propose the inspection date(s), and the activities to be carried out during the inspection.
- The IAEA will respect health, safety, physical protection and other security provisions in force.
- The IAEA shall not communicate to any State, organization or person any information obtained by it in connection with the implementation of this Arrangement.

2. Purpose and scope

The Arrangements are applicable to the pre-nuclear construction phase of the underground rock characterisation facility; the *installation*[1]. This installation is expected to form a part of the final repository of spent nuclear fuel after licensing as a nuclear facility under construction is foreseen to take place after the rock characterisation period of 8–10 years. The emplacement of the spent fuel into the repository is planned to begin 5–10 years later.

The purpose of the early implementation of IAEA safeguards measures is to ensure that the verified design information will be available at the time when the installation is categorized as a Facility under construction, as required by the IAEA safeguards system. Further to this, timely implementation of the appropriate measures by the IAEA will ensure that there is now and at that time credible assurance of the absence of undeclared rock spaces, activities and materials of safeguards relevance.

These Arrangements are aimed at regulating the cooperation between State Authority and the IAEA in the implementation of the required safeguards measures during the whole life time of the repository. These Arrangements are not limiting nor expanding the rights and obligations stipulated in the relevant Safeguards Agreements.

The State will keep the Regional Authority informed about the safeguards procedure until the time when the installation becomes a facility under construction and will be subject to safeguards measures and reporting system also of the Regional Authority.

3. Arrangements

3.1 Scope of arrangements

The arrangements hereinafter describe the activities of the Operator and State Authority that are considered necessary so as to enable the Agency to fulfil its safeguards requirements.

The arrangement covers the following areas:

- Ascertaining the intactness of the host rock as an initial condition;
- Monitoring of the progress in excavation work;
- Generation of the “As-Build-Design-Information” and its verification;
- Measures of the State Authority and the IAEA contributing to the credible assurances of the absence of undeclared materials and activities;
- Review of the implementation.

The implementation of these agreed procedures are facilitated by timely generation and provision of information about the excavation programmes, notifications of particular activities and reports of the results the required safeguards measures. List of the respective documents including associated timing and frequency of their submission are included in the Table attached to these Arrangements as Annex 1.

3.2 Ascertaining the intactness of the host rock at the initial state

The arrangements that will follow rest on the understanding the rock formation at geological disposal site aimed at hosting the repository is confirmed to form an intact rock volume that, prior to the excavation work, did not incorporate any natural or human made voids of

1 The rock characterisation facility is hereby categorized as INSTALLATION. At the time of licensing the INSTALLATION will become part of the nuclear FACILITY under construction.

safeguards relevance. The natural state of the hosting rock mass is disturbed only by a small number of exploratory boreholes and borehole based hydrological tests.

Information from the State to the IAEA

No	Description	Timing / Frequency
3.2.1	Provision of the pertinent information about the host rock and excavation plans	Before underground excavation procedures.

Information from the IAEA to the State

No	Description	Timing / Frequency
3.2.2	Request for further information or for other follow-up activity	ASAP
3.23	Request for access for verification or monitoring purposes	One week in advance[2]
3.2.4	Information about the result of the IAEA activity	Within 60 days after the activity

3.3 Monitoring of the progress in excavation work

The independent State Authority verifies the safeguards relevant data and information generated by the Operator, analyses and evaluates the results. The State Authority communicates its findings i.a. to the IAEA in order to enable it to implement the required measures of the IAEA safeguards system.

Information from the State to the IAEA

No	Description	Timing / Frequency
3.3.1	Main plans and drawings	January/ Once a year
3.3.1.1	Updating	Quarterly / Annually
3.3.1.2	Changes to the plans	2 weeks prior to implement.
3.3.2	Notification of the work that will permanently cover the rock surfaces	
3.3.2.1	Notification of concrete spraying	2 weeks prior to implement.
3.3.2.2	Notification of spraying for safety purposes	ASAP
3.3.2.3	Notification of concrete casting	2 weeks prior to implement.
3.3.3	Notification of any unexpected event or work of relevance to safeguards implementation	ASAP
3.3.4	Provision of progress report	Quarterly

[2] In case instruments are used advance approval shall be obtained in good time.

Information from the IAEA to the State

No	Description	Timing / Frequency
3.3.5	Request for further information or for other follow-up activity	ASAP
3.3.6	Request for access for routine verification or monitoring purpose	One week in advance
3.4.4	Information about the result of the IAEA routine activity	Within 60 days after the activity

3.4 Generation of "As-Build -Design Information" and its verification

The State Authority inspects, in accordance with its inspection plan, the safeguards-relevant measurements carried out by the Operator (Annex 1, Items 9 and 10) and analyses and evaluates the generated data and information so as to ensure that it corresponds with the actual rock space excavated during the reporting period. The State Authority will inform the Operator of its findings, including any corrective actions that need to be taken care prior to the submitting the respective documentation to IAEA.

Information from the State to the IAEA

No	Description	Timing / Frequency
3.4.1	"As-Build-Design Information" document	Quarterly

Information from the IAEA to the State

No	Description	Timing / Frequency
3.4.2	Request for further information or for other follow-up activity	ASAP
3.4.3	Request for access for verification purpose	One week in advance
3.4.4	Information about the result of the IAEA assessments	Within 60 days after the receipt of the A-B-D-I

When assurances are there at IAEA that the "As-Build-Design-Information" document corresponds with the respective excavated structure the State Authority will inform the Operator. The "As-Build-Design-Information" document is thereby validated as a reliable data and information for the future use in safeguards implementation.

The Operator and the State Authority as well as the IAEA will maintain identical copies of these Documents. These Documents will subsequently contribute to the formal Design Information[3] to be submitted to the IAEA through appropriate means and ways at the time the installation would be licensed as a nuclear facility under construction.

[3] DIQ to be developed by the IAEA, BTC by the Regional Authority, European Commission. The submission of the DI will be via European Commission safeguards 200 days prior to emplacement of Nuclear Material in the disposal facility.

3.5 Particular measures by STUK and the IAEA aimed at contributing to credible assurances of the absence of undeclared safeguards relevant materials and activities

The State Authority will periodically audit the Operators system and its performance. Further to that, the State Authority will regulate the conditions and circumstances as well as activities in the area so as to be in a position to judge possible safeguards relevance.

The State Authority will periodically assess the results of its activities, including such as environmental monitoring and area surveillance, and inform the Operator, or any other relevant party, of its findings, including any issues that need to be further clarified.

Information from the State to the IAEA

No	Description	Timing / Frequency
3.5.1	Findings and issues of relevance to safeguards	Quarterly

Information from the IAEA to the State

No	Description	Timing / Frequency
3.5.2	Request for further information or for other follow-up activity	ASAP
3.5.3	Request for access for verification or monitoring purposes	One week in advance[4]
3.5.4	Information about the result of the IAEA assessments	Within 60 days after the receipt of the A-B-D-I

3.6 Review of the implementation

The State Authority and the IAEA will conduct a review meeting on implementation each year. The purpose is to ensure that all issues of safeguards relevance have been and, in case of unresolved questions or anomalies, will be timely and appropriately addressed.

[4] In case instruments are used advance approval shall be obtained in good time.

ANNEX 1 Access to information, people and physical premises to enable IAEA safeguards measures

Activity	Type	Availablility of info	Updating	Notification
1. Main plans and drawings (relevant parts)	Annual	January	Quarterly	
Changes to the plans	Ad-Hoc			2 weeks prior to impl.
2. Surveying programme (As-build data gen.)	Routine	Quarterly	NA	NA
3. Concrete spraying	Semi-Ann.	Quarterly	As soon as known	2 weeks prior to impl.
4. Spraying for safety purposes	Ad-Hoc	Need to know basis	NA	As soon as possible
5. Concrete casting	Semi-Ann.	Quarterly	As soon as known	2 weeks prior.
6. Monitoring vibration and acceleration	Periodic	Quarterly	NA	NA
7. Microseismic monitoring	Periodic	Quarterly	NA	NA
8. Geo-environmental monitoring	Continuous	twice a year	As soon as known	3–6 months prior
9. On-site inspections by State Authority	Routine	See inspection plan	NA	NA
10. Internal audit by State Authority	Annual	See QA-manual	NA	NA
11. As-build design information	Periodic	Quarterly	NA	NA
12. Report by State Authority	Annual	in February	NA	NA
13. Regional Authority's visits	Ad-Hoc	As need araises	NA	NA

Note: Physical access to premises is constrained by safety and security precautions of the facility.