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SAFEGUARDS FOR THE GEOLOGICAL REPOSITORY AT OLKILUOTO IN THE PRE-OPERATIONAL PHASE

Final report on Task FINSP C 01374 of the Member States' Support Programme to IAEA Safeguards

Olli Okko, Juha Rautjärvi

STUK • SÄTEILYTURVAKESKUS
STRÅLSÄKERHETSCENTRALEN
RADIATION AND NUCLEAR SAFETY AUTHORITY

Osoite/Address • Laippatie 4, 00880 Helsinki
Postiosoite / Postal address • PL / P.O.Box 14, FIN-00881 Helsinki, FINLAND
Puh./Tel. (09) 759 881, +358 9 759 881 • Fax (09) 759 88 500, +358 9 759 88 500 • www.stuk.fi

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Abstract

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 are proceeding to the underground phase in 2004 when the excavation of the tunnel system for bedrock characterisation at the repository site begins. The nuclear licensing procedure is scheduled to take place in 2010–2012, after the geological investigations have reached the target depths and the lay-out plan for the repository is developed and assessed. 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 safeguards approach for this pre-operational phase at Olkiluoto site is suggested. At the present phase the main obligation is to be ensured about the absence of undeclared activities at or near the repository and during the excavation of the investigatory galleries and the verification of the excavated rock space and its geometrical volume. The influence of the excavation activities will be verified against the baseline information collected by the operational company responsible for the disposal during the site investigations.

In order to identify the site-specific safeguards needs, the national expert group evaluated the IAEA recommendations and implemented the National System to safeguard the repository site at Olkiluoto. Because underground excavation works in the hard crystalline rock of Olkiluoto must be carried out using drilling methods, the safeguards-relevant monitoring is proposed to be focused on mining-related activities. The passive seismic monitoring and satellite imagery techniques are suggested for these purposes. Both methods give indications on the activities near or at the repository as shown in the baseline data collected by the National System in 2002–2004. In addition, the hydrological monitoring near the site is also supposed to give signals as unexpected changes in water pressure or chemistry due to unknown openings in the rock volume. However, these remote sensing methods are insensitive to the amount of rock volume excavated or to the volume underground space developed. Therefore, the design information generation and verification for safeguards purposes should be incorporated to the progress in tunnelling and to the geological mapping of the tunnel walls in the subsurface before the walls are possibly reinforced using spray concrete or other techniques that will prevent the rock wall inspection and verification activities afterwards.

Preface

The Finnish Support Programme for the IAEA safeguards has undertaken tasks aimed at developing efficient safeguards concepts and techniques for the final disposal of spent fuel at the projected facility in Olkiluoto, Finland. The Task FIN A 1184 concerning the preliminary concept for safeguarding spent fuel encapsulation plant in Olkiluoto has been reported earlier as STUK-YTO-TR 187 / June 2002.

This report provides the results of the Task FIN C 1374. Due to the complex nature of the subject matter, the task outline had to be revised in order to maintain focus on the current needs arising from the necessities to implement appropriate measures at the underground research phase at the proposed repository location, and to establish and maintain the knowledge base enabling efficient safeguards at the final repository itself.

These efforts of the Finnish Support programme are understood to contribute directly to the IAEA Research and Development Programme for Nuclear Verification 2004/5 and particularly to the objectives set for in its Project SGCP-03. This report is generated parallel with the progress of the Programme for Development of Safeguards for Final Disposal of Spent Fuel in Geological Repositories, Task JNT C 1204. This Finnish Task contributes to the establishment of functional, non-intrusive, and cost-effective site-specific safeguards measures applicable at the geological circumstances at Olkiluoto, Finland.

Contents

1 Introduction

Final disposal of spent fuel and other nuclear materials may occur in geological repositories at depths of 250–1000 meters below ground level. The operational life of a repository is expected to be 20–100 years before it is closed, backfilled, and sealed. The repository plans in Finland are to dispose 2600–2700 tons of spent fuel the 40–50 years of service of four reactors at Olkiluoto and Loviisa power plants in crystalline rock at a depth of 300–500 m near the Olkiluoto facilities. In addition, it will considered that during the operational phase the underground disposal facilities are to be enlarged to dispose also the spent fuel of the future reactors. The approximated spent fuel from the planned third reactor at Olkiluoto will raise the present estimate up to 5800 tons after the 60 years of the service.

Facilities for the final disposal of spent fuel, though still in the planning stages, are being designed and submitted for licensing approval in several countries. Site characterisation activities are being conducted and exploratory facilities are being excavated. The United States (U.S.) exploratory facility at Yucca Mountain is complete and will become the main tunnel of the U.S. repository when the facility is licensed. Belgium, Switzerland, France, Germany, Canada and Sweden have excavated underground laboratories to confirm their repository concepts. In Finland, the proposed underground investigation gallery may become part of the final repository. Finland designated the Olkiluoto site for its national geological repository in May 2001; whereas, the United States designated the Yucca Mountain site as its repository in July 2002. Sweden is expected to designate its repository location in 2006. The U.S. repository is scheduled to begin operation in 2010, Sweden in 2017, and Finland in 2020.

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. The stepwise process is outlined in Figure 1. The early programme was focused on site selection to be carried out by the generators of spent nuclear fuel. After the comparison the several sites, the Olkiluoto site was considered to represent typical Finnish bedrock and an application to site the final disposal repository in the Olkiluoto area was made. This was accepted by the local municipality, the authorities, and finally endorsed by the Parliament. After the Decision-in-Principle the Implementer (Posiva Oy, owned by the power companies) has focused the site-specific investigations in Olkiluoto. In addition to the geological borehole investigations, an underground tunnel system is planned to be excavated in the Olkiluoto research site for the rock characterization purposes. These tunnels may by linked to form a part of the final repository, in case the investigation confirm this to be the acceptable solution.

The Finnish implementer was licensed for the excavation of the underground research laboratory in 2003 by the local municipality of Eurajoki. Preliminary works have already begun, and the excavation will begin in 2004. Since no nuclear material is planned to be transferred into this research laboratory during the research phase of about 6–8 years, the national Nuclear Energy Act is not applied in the municipal licensing procedure, although the Radiation and Safety Authority (STUK) reviewed the application. In general, the implementing company has openly informed the authorities about its site characterization and research plans. Owing to this principle of transparency, the main drawings and a scientific monitoring programme are also published (Posiva 2003). Therefore, this geological, hydrogeological and rock mechanical monitoring and research programme can also be evaluated by the authorities and be applied as a part of the safeguards measures. Moreover, in order to facilitate the licensing procedure of the final disposal facility, STUK has initiated safeguards measures to be applied during the construction period. The procedure is focused to fulfill the DIV requirements described in the International Atomic Energy Agency's Policy Paper 15 (IAEA, 1997). The Policy Paper, derived from the work of the IAEA SAGOR (Safeguards for the Final Disposal of Spent Fuel in Geological Repositories) Working Group, is generic guideline for safeguarding geological repositories. Therefore, the generic approach must be applied taking in to account the local geological features, facility concept, excavation and research activities, and the existing legislation.

The successor of the SAGOR Group, 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

1983	Screening of candidates for site investigations (134 areas)
1986	Evaluation by authorities
1987–	Preliminary site investigations (5 sites)
1992– 94	Reporting and review by authorities
1993–	Detailed site investigations (3 sites)
1996–97	Interim Reporting and review by authorities
1997	Detailed site investigations continued (4 sites)
1999	Application for DiP and proposal for siting
1999–2001	Review by authorities; decision by Government; ratification by Parliament May 18, 2001
2000–2002	Planning of site confirmation and underground characterisation
2003–	Review of plans by authorities
2004–	Underground rock characterisation
2006–	Interim Reporting and review by authorities
2010–12	Application for construction license
2011–14	Review of the application and decision by Government; Starting point for the construction of the final repository
2020	Application for operating licence
2021	Review of application and decision by Government; Starting point for final disposal

Figure 1. Major events in the programme for disposal of spent fuel in Finland.

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 after the publication of the generic work of the SAGOR Group, particularly during the last meetings of the Group, in Oskarshamn 2002 and in Rauma 2003. This Finnish Task C 01374 presents the national approach to establish the site-specific safeguards approach, also applicable to other organisations.

2 The IAEA safeguards 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). The IAEA is entrusted for conducting independent verification activities to provide assurance of the nondiversion of nuclear material from declared activities and of the absence of undeclared nuclear materials and activities. The safeguards objective as applied to an operating repository is to provide a high level of assurance that the quantity of nuclear material contained in the spent fuel declared to be transferred into a repository is transferred into the repository and that undeclared removal of nuclear material would be detected. The safeguards objective as applied to the post-closure phase is to provide a high level of assurance that an undeclared breaching of integrity of a repository is detected and that continuity of knowledge of the nuclear material content of the repository is not lost because of a safeguards system failure.

A geological repository is a unique facility type for the perspective of international safeguards because of its construction into the bedrock, the long construction period, and the continuing safeguards requirement after facility closure. Because of these, the IAEA should recognize that different design information generation and verification time schedules apply than have typically been used when applying safeguards to surface facilities.

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 unique challenges. First, the space, into which the repository will be constructed and the underground areas contiguous to the boundaries of the repository, cannot be directly observed. Second, once emplaced, the IAEA will no longer be able to reverify the inventory of nuclear material contained in the repository because of the backfilling of the emplacement drifts. Thus, should continuity of knowledge of the nuclear material content of the repository be lost, that knowledge cannot be restored.

Geological disposal facilities will be developed over a period of at least a few decades. Key decisions, e.g. on the disposal concept, siting, design, operational management and closure, are expected to be made in a series of steps. Decisions will be made based on the information available at each step and the confidence that can be placed in that information. The step-by-step approach also allows opportunities for independent technical reviews, regulatory reviews, and political and public involvement. Decisions on the need for continued monitoring could be made by future generations. However, before the start of construction, during emplacement and at closure, the understanding must be sufficient to support the safety and safeguards case that satisfies the applicable 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. Nine Member States and two international organizations contributed to the SAGOR Programme recommendations.

International Atomic Energy Agency, Policy Series Number 15, dated June 1997, states the following policies, among others, with respect to geological repository safeguards:

"3.1.1 Spent fuel disposed in geological repositories is subject to safeguards in accordance with the applicable safeguards requirements. Safeguards for such material are maintained after the repository has been back-filled and sealed, and for as long as the safeguards agreement remains in force. The safeguards applied should provide a credible assurance of non-diversion.

"3.1.2 The safeguards system for such a repository should be based on: verification of design information during design, construction, and operation; verification of receipts and flow that no nuclear material is removed by any declared or undeclared access routes; and maintenance of continuity of knowledge on the nuclear material content."

"3.1.4 Safeguards requirements should be integrated into the repository design at an early stage in order to establish functional, non-intrusive, and cost-effective safeguards measures. Consultations between the State and the IAEA should, therefore, start at an early stage to agree on the safeguards measures in the repository."

"3.1.7 The State should provide the following information as early as possible:

- draft plans of a geological repository site; …
- description of intended exploratory underground works for the geological repository; …
- information on existing local mines; and
- any other information that might be identified by the IAEA as relevant for the purpose of safeguards.

"3.3.1.2 The Agency, in collaboration with the State, should establish all pertinent information about the original undisturbed site (i.e., zero-point checking), preferably before excavation begins, in order to plan for safeguards measures."

Monitoring will be required during each step of disposal facility development. Purposes may include providing baseline information for later assessments, assurance of operational safety and facility operability, and measurements to confirm conditions consistent with long-term safety. The latter includes shaft and tunnel stability, control of drainage water, control of underground air conditions, operability of waste handling and other equipment, and radiological control. Monitoring programmes must be designed and implemented so as not to reduce 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). In Finland, the national expert group LOSKA, consulting the national authority, reviewed these measures and considered a few of these techniques to be suitable to be applied at the Olkiluoto site (STUK-YTO-TR 199). During the pre-operational phase the selected measures, techniques and procedures should be proven and efficient practices developed.

3 Geographical site of the Olkiluoto facility

The excavation of the final disposal repository can be regulated according to the national legislation. In Finland the Nuclear Energy Act is modified to adopt the requirements of the Nuclear Non-Proliferation Treaty (NPT) and its Additional Protocol, INFCIRC/540. However, at present the modifications are not yet in force, since the INFCIRC/540 shall be ratified simultaneously in the European Community, most probably during 2004. Anyhow, the national system safeguarding the development of the repository is suggested to follow these international requirements and obligations.

The gallery in the form of a research tunnel is named Onkalo by the Implementer. This Underground Rock Characterisation Facility (as named by the Implementer) is located within the geological research site at Olkiluoto, apart from the nuclear power plants (Figure 2). These terminological wordings are widely used in the geological society but unfortunately they are inconsistent to those of the Additional Protocol (AP), according to which the facilities and sites are to be declared as the Article 2 of the AP states that "Each State and the Community (Euratom Safeguards) shall provide the Agency (IAEA) with a declaration containing the information identified in sub-paragraphs".

The subparagraph, Article 2 a (iii) requires "A general description of each building on each *site*, including its use and, if not apparent form that description, its contents. The description shall include a map of the *site*."

Site is defined in the Article 18b as follows:

"'Site' means that area delimited by the Community and a State in the relevant design information for a *facility*, including a closed-down facility, and in the relevant information on a location outside facilities where nuclear material is customarily used, including a closed-down location outside facilities where nuclear material was customarily used (this is limited to locations with hot cells or where activities related to conversion, enrichment, fuel fabrication or reprocessing were carried out). 'Site' shall also include all installations, co-located with the facility or location, for the provision or use of essential services, including: hot cells for processing irradiated materials not containing nuclear material; installations for the treatment, storage and disposal of waste; and buildings associated with specified activities identified by the State concerned under Article 2(a)(iv)." The Article 2a(iv) is a request to describe the scale of operation for each location engaged in the nuclear-related manufacturing specified in Annex I to the Protocol.

Moreover, '*Facility*' means:

(i) a reactor, a critical facility, a conversion plant, a fabrication plant, a reprocessing plant, an isotope separation plant or a separate storage installation, or

(ii) any location where nuclear material in amounts greater than one effective kilogram is customarily used.

The final disposal repository site at Olkiluoto shall include several buildings that will serve in the future as facility and also as "essential services for the treatment, storage and disposal of waste", if spent fuel is considered as waste. The geographical site shall include the main encapsulation plant (the future Facility, where one effective kilogram is customarily used) and of a large underground repository (the future Facility, as a separate storage installation). The design of the sub-surface facilities will continue during the rock investigations, and the licensing procedure is scheduled to take place in 2010–2012. In the preparatory phase, an underground research gallery will be excavated. The final repository is planned to be linked to this research gallery according to the research results. Moreover, the geographical or geometrical siting of the repository may change also during the operational phase.

The installations, i.e. buildings to facilitate the underground repository shall be built in the land area owned by TVO, co-located at the distance of a few kilometres from the present NPPs. According to the current Finnish legislation, underground constructions are not included in the gross floor area of the building on surface, thus the municipal civil construction permit does not give restrictions on construction of the underground research laboratory. However, it is planned to be constructed according the long-term safety assessment. It is not straightforward that the development of this underground space can be regulated and inspected as part of the “Nuclear Facility” or “Location outside facilities” at the “site”. However, it is “relevant to the development of nuclear fuel cycle

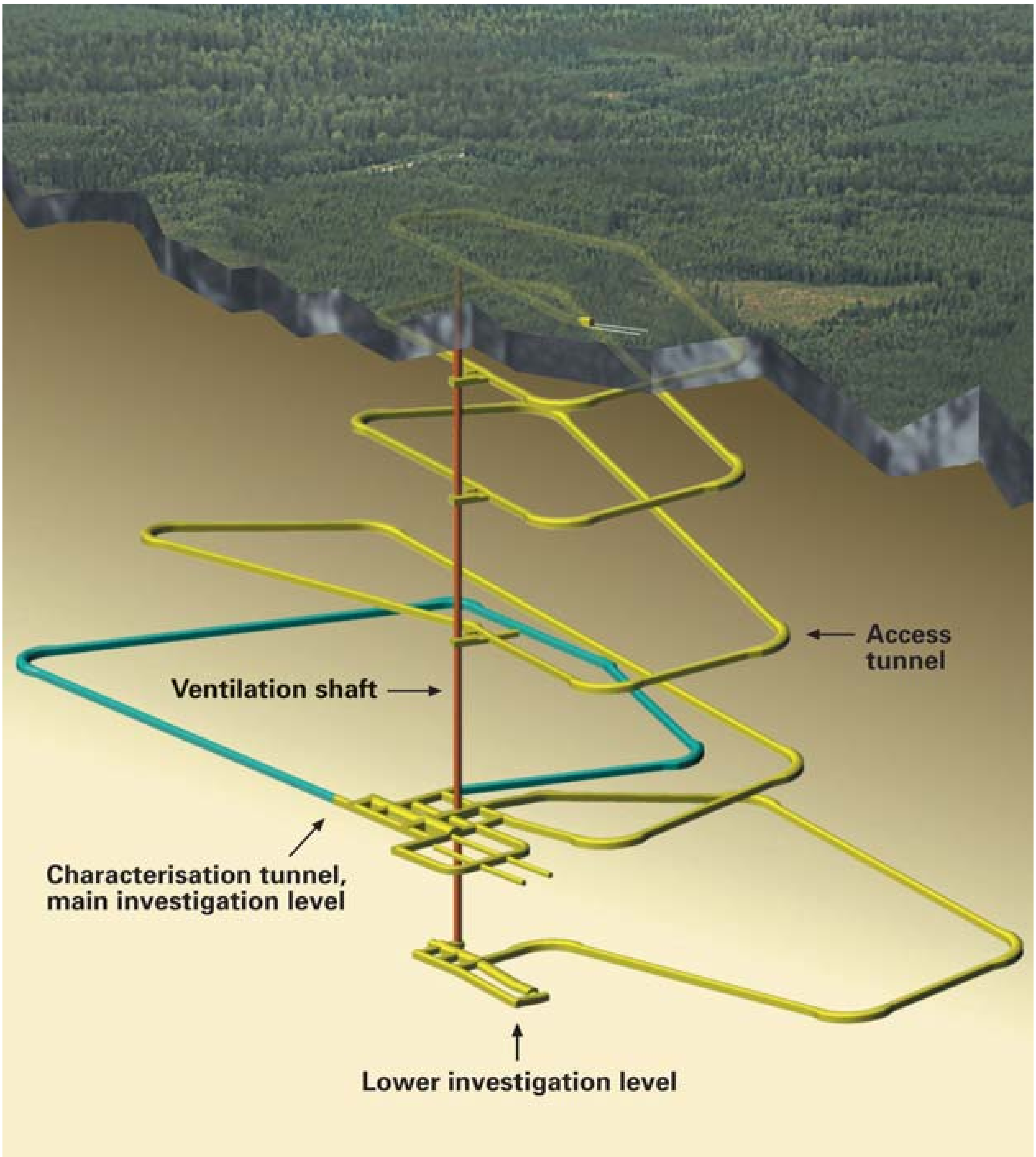

Figure 2. The underground rock characterization laboratory Onkalo to be excavated at Olkiluoto (Posiva Oy, 2003).

as approved by the appropriate authorities" and thus considerable under the Article 2a(x).

According to the present Finnish legislation, the plan to construct an underground rock characterisation facility consisting of a ramp, tunnel and shaft is not subjected to the Nuclear Energy Act. However, the possibility of having this underground space licensed to be a part of the repository shall be considered already during the construction phase. Also, the IAEA Policy Paper 15 also suggests that "The Agency, in collaboration with the State, should establish all pertinent information about the original undisturbed site, preferably before excavation begins, in order to plan for safeguards measures. Attention should be given to investigatory shafts or tunnel, which may in some cases be excavated before the decision to build a repository has been made."

Therefore, the underground characterisation and research programme with an extensive environmental monitoring will be reviewed also by the Radiation and Nuclear Safety Authority. Owing to the principle of public transparency, the main drawings (Figure 2) and the scientific monitoring programme are also published by the Implementer (Posiva 2003). Moreover, this geological, hydro-geological and rock mechanical monitoring and research programme can also be evaluated by other independent scientists and the authorities, and the monitoring results can, as applicable, contribute to safeguards measures. Moreover, the operator also willing to allow additional monitoring instruments to be placed at the site, if considered to be necessarily. The independent verification methodology can be defined in co-operation with the operator and landowner.

Owing to the present conditions and development with the repository, the FINSP invited the IAEA and the Expert Group to visit the Olkiluoto geographical site and provided the Agency with pertinent information during the one-week symposium held at Rauma Sept. 29 – Oct. 4, 2003. Later, on November 18, the Director General of STUK invited the IAEA to start negotiations concerning the implementation of safeguards measures during the pre-operational phase of the final repository. In this official letter, a summary presenting the background material discussed at Rauma was also submitted to the Agency. The safeguards criteria, as applicable, are to be fulfilled already during the excavation of the first gallery in 2004.

4 Design and operational features of the repository through out the lifetime

The disposal facility will consist of the surface installation including the encapsulation plant and the underground facilities. The nuclear spent fuel canisters filled in the encapsulation plant are lowered in a lift or in a ramp to the underground final disposal repository. The repository will consist of tunnels excavated at a depth of hundreds of meters at 25 m distance from each other. These repository tunnels are connected by transport tunnels (Figure 3). Apart from the canister transfer shaft, the facility is connected to the ground surface by a personnel shaft and a working shaft, also a ramp in under consideration and proposed for the research tunnel of Onkalo. In general, the siting of these facilities at the territory of Olkiluoto is not yet designed. The principle is discussed below.

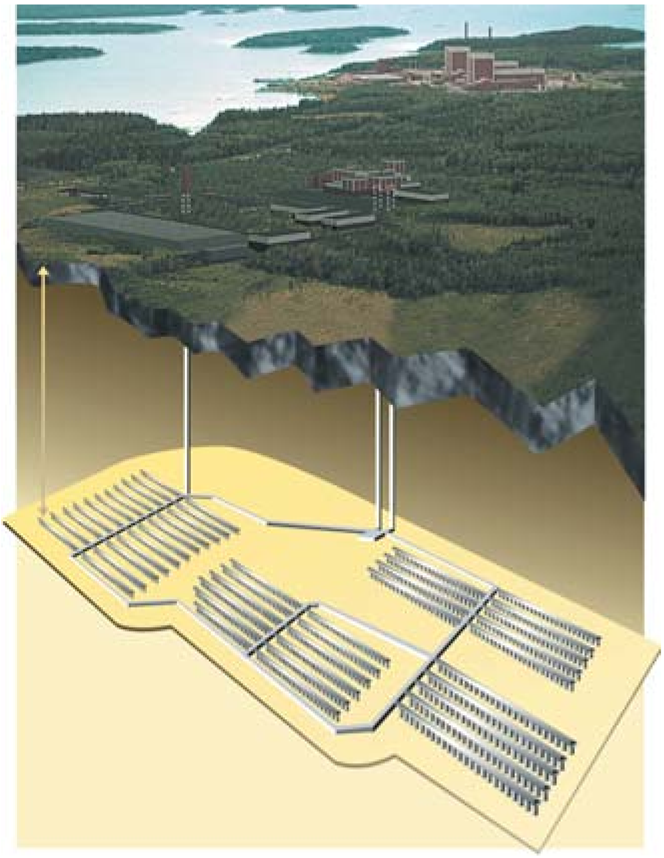

Figure 3. Generic layout of the disposal facility at Olkiluoto (Posiva 2003).

According to the Implementer's present view (Posiva Oy, web-site 2003):

"The final disposal canisters will be made of nodular cast iron, enclosed in a watertight, 5 cm thick copper shell. The canisters will be emplaced in holes drilled at the bottom of the tunnels excavated in the bedrock. The canisters will be emplaced in holes drilled at the bottom of the repository tunnels, spaced at a few meters from each other. The canisters are then surrounded with bentonite clay, which expands when it absorbs water. The clay not only prevents direct water flow to the surface of the canister, but also protects the canister against minor bedrock movements. The rock isolates the fuel so that it can never be harmful to the organic environment. By emplacing the canisters deep in the bedrock, the nuclear waste is isolated from any events taking place on the ground surface. This also prevents unintentional penetration by man into the final disposal facility. The depth of the repository ensures sufficient isolation against e.g. turmoils caused by future ice ages.

The bedrock protects the waste against external influence, creates mechanically and chemically stable conditions in the final disposal repository and restricts the amount of water coming into contact with the final disposal canisters. The research results obtained so far indicate that groundwater movement is minimal inside the rock at a depth of hundreds of meters. The water is also almost oxygen-free so that its corrosive influence on both the canisters and the spent nuclear fuel is negligent. If the spent fuel for some unforeseeable reason should come into contact with the groundwater, the materials dissolved from it would be trapped in the bentonite and the bedrock round the canisters.

The bedrock will stop any possible radiation emitted from the waste canister, but this is not the primary reason for burying the nuclear waste in a depth of several hundred meters: a solid rock course of just of few meters would be enough to dampen the radiation to the level of natural background radiation.

When the last canisters have been emplaced in the repository, the encapsulation plant is decommissioned, the tunnels are filled with a mixture of bentonite and crushed stone and the shafts leading to the repository are closed. The final disposal repository will require no monitoring after it has been decommissioned.

After decommissioning, the use of the land above will in no way be restricted by the repository tunnels. When in operation, the final disposal facility will cover a ca 40 hectare land area. After the facility has been closed, this land area can be used for any purpose considered suitable.

In practice, the safety of the final disposal of spent nuclear fuel is based on several technical and natural release barriers which prevent and slow down the release of radioactive materials from the final disposal repository into the bedrock and into the organic nature. These barriers include the solid state of the spent fuel, the double construction of the final disposal canister and the bentonite clay in which it is enclosed. The final barrier is formed by hundreds of meters of rock between the final disposal repository and the organic nature" (Posiva Oy 2003).

5 Site-specific general safeguards objectives

The Olkiluoto area is located in western Finland where the 1800–1900 million year old bedrock in mainly composed of metasedimentary migmatic mica gneisses. These gneisses are cut by granodiorite, coarse grained granites and granitic pegmatites. About 4 % of the area of the present Olkiluoto Island, where the NPPs and the disposal site are located, is represented by outcrops of these crystalline rocks, which are present everywhere at a depth of a few meters. The thickness of the soil cover varies, in general, between 2 and 7 meters, the deepest depressions are 20 m deep. The Olkiluoto area is flat; the highest point of the Olkiluoto Island is 18 m above sea level. The access tunnel to the Onkalo laboratory is proposed to begin at one of the local rocky hills at the level of 9–10 meters above the present sea level. Therefore, all the activities related to the underground facilities are taking place in the hard rock. The excavation itself is going to be done using the classical drilling and blasting method. The ventilation shafts will be first made by the raise boring technique and later slashed up to larger diameter using the drilling and blasting techniques.

The underground repository of operating waste was excavated near the NPPs at Olkiluoto during 1988–1989. These caverns were sited in the even-grained grey gneiss, also called tonalite owing to its igneous-like texture. The mineralogy is the same in tonalities and mica gneisses. This rock is considered to be most stable one in Olkiluoto. However, a few water-conductive fracture zones were cut during the excavation. In general, an average of 0.7–1.1 fractures per scan line meter was encountered during the geological characterisation of the tunnels. The majority of the fractures were filled, kaolinite and chlorite are the most common fracture infillings, but carbonates, sulphides, graphite and clayey mineral occur abundantly. The same infilling are also present in the deep boreholes cored to characterise the final disposal site to a depth of 500 m. During the construction of the repository of operating waste, the mostly fractured intersections of the tonalitic tunnel wall were reinforced using bolts and concrete. According to the geological investigations most of the rock volume at Olkiluoto consists of the more deformed mica gneiss. Therefore, most tunnels and rock spaces of the deep repository must be sited in the deformed rock in which more grouting than in the tonalitic rock can be expected.

According to the plans, the access tunnel to the Onkalo 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. The tunnels and the shaft will be reinforced by bolts, sprayed concrete and possibly also steel mesh or cast concrete structure reinforcements. 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 and construction activities to recognise the most suitable solutions in advance, and to handle possible unexpected changes in the layout of the Onkalo. The design information generation and verification for safeguards purposes should also be linked to this phase. The verification of the progress in tunnelling should be 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 facility.

The possible existence of a clandestine tunnel at the repository site of Olkiluoto is difficult to prove. There are several geophysical techniques that are applicable to detects voids and openings within the bedrock. However, the effectiveness of these 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 fractures in the bedrock. Based on these results it can be assumed that the number geophysical anomalies interpreted to originate from unknown bedrock features between known boreholes is rather high; in particular the conductive fracture infillings listed above will reflect radar waves of any ground penetrating radar instrument as already observed in the site characterisation studies. Therefore, the direct mapping of unexpected tunnels beyond the reinforced tunnel wall using geophysical techniques in the repository will mainly generate fuzzy information for the geological bedrock modelling. The origins of all of anomalies can not be verified without extensive drilling and coring.

The excavation of a clandestine tunnel will introduce environmental effects that may be detected indirect. In order to reach the depth of 500 m with a truck, a sloping tunnel is required. Assuming the slope of 1:10 the length of the tunnel must be at least of the order of 5 km, like the ramp of the Onkalo. The tunnelling should be carried out in an undetectable way. However, the bedrock must be blasted; maybe a large coring machine could be applied for tunnelling. Probably, a large diameter drilling equipment could be applied for the direct access to the repository. 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.

Until the construction of the Onkalo exploratory gallery is initiated, the bedrock remains undisturbed except for the boreholes used for initial site characterization, and the already ongoing preparatory works related to removal of vegetation and soil cover. The boreholes will be used also during the monitoring of the effects of the excavation to the natural conditions. Therefore, hydrogeological and –chemical monitoring will take place during the construction and operation period. Also, the geophysical and geological site characterisation programme will continue with the development of the research tunnels. The proposed monitoring programme (Posiva 2003) is addressed mainly to long-term and operational safety during the construction period of the Onkalo. Small enlargements to the proposed programme would give signals also from rock masses and hydrological condition also in the safeguards-relevant neighbourhood of the Onkalo. Safeguards relevant features of that procedure need to be identified and, if necessary, additional elements of safeguards relevance incorporated.

6 Potential monitoring methods and procedures for the Olkiluoto site

The IAEA Programme for the Development of Safeguards for the Final Disposal of Spent Fuel in Geological Repositories (SAGOR), comprising eight Member State Support Programmes, European Commission, and IAEA was launched in 1988. Additional work was also undertaken by the Canadian, German, Swedish and U.S. Safeguards Support Programmes. These programmes performed diversion path analyses for generic facility geological repository designs and developed recommendations on IAEA safeguards requirements and safeguards approaches. The generic safeguards approaches for operating and closed deep geological repositories were defined in the IAEA SAGOR report (STR-312, 1998). The generic safeguards approaches were defined more in detail by the expert's of the SAGOR group meeting in 2002 (STR-338, 2003). Before these approaches were developed and agreed, it was necessary to first define the model repository. This definition remains valid and is provided here for information.

6.1 Model geological repository

The model geological repository has a large number of excavated vaults, or disposal galleries, access tunnels to the vaults, shafts for surface access and ventilation, access ramps or drifts and various surface facilities to service the repository. It is assumed that several disposal vaults would be excavated and prepared for use prior to the receipt of the first waste package. It was also assumed that excavation would continue whilst waste packages were emplaced elsewhere within the facility.

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 spent fuel will arrive on site in sealed containers from a spent fuel conditioning and encapsulation facility. The safeguards requirements are based primarily on the need to maintain 'continuity of knowledge' (CoK) on the nuclear material items. 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. Working in combination, C/S and DIV will contribute towards CoK.

The SAGOR Programme assumed that the model repository would have an operating lifetime in the region of 40–50 years. After the last waste container is received and emplaced there is likely to be a period of several years during which time the evolution of the facility is closely monitored. This period will provide assurance that systems continue to operate as expected – systems in this context refer to both 'man-made' mechanical and 'natural' geological/near-field systems. This period will be the precursor to active decommissioning operations that will include both surface and underground facilities. Backfilling of the emplacement vaults and access tunnels is expected to take place at some time when there is sufficient confidence in the facility. During the closure period following backfilling of all drifts, tunnels, shafts, boreholes and surface facilities, certain equipment will remain in place in order to provide a monitoring role for a period of time until the regulatory authorities deem there is no further requirement. At this time, the safeguard measures applied will necessarily be refocused in order to give assurance that nuclear material is not being removed for non-peaceful purposes. The role of geophysical (e.g., passive seismic) methods, environmental sampling, and satellite and aerial surveillance techniques will become more prominent. These will be part of an active inspection programme intended to detect undeclared operations that may be used as a means for gaining access to the nuclear materials.

It should be noted that to be entirely successful the safeguards approach will have to be dynamic. That is to say it will require regular review and modification in order to meet changing circumstances. Operator, State and Inspection Authority liaison will be a pre-requisite in order to implement an effective and demonstrable safeguards system that meets the safety goals of the repository. The measures applied will also clearly change throughout the lifetime of the repository (construction, operation, post-operational phase and post-closure).

The diversion paths identified for the model repository include the removal of spent fuel canisters or containers from above and below ground, through various routes. It is expected that a potential diverter would consider associated activities, such as substitution, to either conceal or delay detection.

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 redundancy. The safeguards approach may be 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. All potential access points to the repository would be rigorously monitored to ensure that no undeclared items leave or enter the underground facilities.

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 precise construction of the facility. Environmental sampling in the repository is also being considered.

6.2 Olkiluoto repository

The construction and operational features of the Olkiluoto repository are described in chapters 3 and 4. The IAEA Expert Group visited 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. 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.

The Olkiluoto rock characterisation tunnels are planned to be excavated in the well-investigated area of approximately 1 km^2. The geological characterisation of the geographical site is based mainly on more than 25 boreholes drilled for the site characterization at the repository depth. This Onkalo site will be actively monitored during the construction phase using observations and sampling carried out with the aid of the boreholes and direct observations in the sub-surface. This near field monitoring covers an area of 5 km^2; whereas, the remote operated geophysical and satellite methods can be addressed to a larger area. Considering the possible construction of a sloping tunnel with the slope of 1:10, requested for the heavy transport vehicles, the activities should be monitored within the distance of at least 5 km around the repository. The expert group considered the radius of 10 km to be reasonable for monitoring.

6.2.1 Earth observation techniques

Earth observation techniques are one tool to monitor a repository. Using earth observation from satellites, activities and changes on surface can be monitored. The most suitable targets for earth observation include monitoring of building and road construction activities and quarrying. The development in the site can be monitored in a straightforward manner by overlaying images from different dates. Change events can be accurately located. Also different image types can be overlaid with each other, e.g. optical imagery and synthetic aperture radar (SAR) imagery. The images can also be overlaid on map databases. Archived images can be easily reanalyzed.

Although the earth observation techniques are widely used, also by the IAEA, a site cannot be continuously monitored. For instance, the frequency of data acquisition using space-borne or airborne imaging is too low to monitor ground traffic. Optical satellite data cannot be acquired through cloud or nighttime. During winter image quality is often poor also during clear days due to long shadows and low intensity of reflected radiation. Snow cover makes automatic image analysis more difficult particularly when only part of the ground is snow-covered during autumn or spring. The geographical location of Olkiluoto at 62 latitude and the four seasons, introduce these limitation to be considered.

The earth observation techniques can be applied as an unannounced control technique. If the repository site is monitored using earth observation only once a year or less frequently, and if there is a flexibility in the selection of acquisition time, optical satellite data with sub-meter resolution is the best and possibly an adequate alternative. If more frequent image acquisition is desired the monitoring should involve using synthetic aperture radar (SAR) that can acquire imagery under all weather conditions during all seasons. Within the coming five years, space-borne SAR data with few meters resolution will be available.

6.3 Radiological Monitoring

Radiological monitoring is a key tool that provides assurance to authorities and the local community that nuclear facilities are being safely operated. It is a well understood technology with a large expert base. Radiological monitoring is been carried out remotely by installed devices or by collecting samples during site visits. The environmental monitoring at Olkiluoto is carried out by STUK already before of the operation of the NPPs begun. This monitoring gives a reasonable background, or baseline for comparisons while monitoring the chances introduced by the future operations in Olkiluoto.

Any attempt at re-processing within the repository will release both particulate and volatile radionuclides. Particulate is likely to be contained by HEPA filters, but detectable amounts of volatile isotopes could escape from the hot cell and leave the repository in exhaust air or in wastewater. Small quantities of volatile radionuclides would also be released if a used fuel canister were opened within the repository. Therefore, the radiological monitoring can be suggested to be carried out at the repository site and in the future also within the disposal facilities.

In addition, naturally occurring radionuclides are encountered also at Olkiluoto; particularly in granite and clay, elements in the ^{238}U series and also ^{40}K are common. ^{226}Radium decays to radon gas, which is commonly encountered in Finland, also at the present Olkiluoto facilities. New excavation can lead to a significant release of radon. Any radon anomaly might be associated with new excavation.

6.4 Geophysical sounding and monitoring

Geophysical techniques are typically developed to measure physical rock properties and to detect chances (i.e. geophysical anomalies) in these as well as to map continuing interfaces in the subsurface. The measured readings and especially the anomalies are later related to changes in rock properties using different types of inversion techniques. The geophysical techniques can be divided in two main categories, those requiring active triggering of the geophysical primary field (sounding) and those based on the passive monitoring the geophysical field.

Typically, the geophysical techniques are applied in such a manner that the expected features should introduce the expected anomaly; which is target in field surveys. The observed anomaly is later analysed using software and finally quantified in terms of rock properties. Therefore, the active methods require skilled personnel to select the sensitive instruments and to operate them manually or automatically. Even within one technique there are instrument properties (e.g. source and recording frequencies, recording parameters) and the operator dependent factors (selected sensor locations, sounding frequencies, gaining functions in recording and processing, etc.) which affect the results. Moreover, the processing of the recorded data needs professionals. Typically, the geophysical data need to be processed and analysed after the field work. The analysis, often called interpretation procedure, commonly requires also the presence of the end-users, often geologists who have given the particular target for the field survey.

The commercial use of the geophysical techniques in the hard rock environment is mainly within the mining industry. Some of the methods are also used to locate water-bearing features in rock. These methods are sensitive also to voids in rock mass and therefore can be used for safeguards purposes. A void in rock can be located using several methods and by combining the results of several inversion processes. The most relevant geophysical methods (gravity, seismic, electromagnetic) are based on the difference in physical properties of water or air in contract to intact rock. Those methods identified to have safeguards relevance are described in the SAGOR-reports. However, the theoretical detectability of any object depends on the size of the object and on the distance to the object and the difference in the physical properties in reference to the selected technique. Therefore, the suggested methods should be analysed with reference to the physical rock properties observed during the site characterization of Olkiluoto. Owing to this experience the applicable methods must be proven for safeguards implementation.

6.4.1 Passive Seismic

Passive seismic monitoring can be carried out at various frequencies. Short period (0–50 Hz) seismic monitoring is often carried out by national authorities to monitor natural seismicity. Microseismic monitoring (1–500 Hz) is used to monitor rock stress during intensive mining. Continuous passive seismic monitoring is likely method for the detection of excavations that introduce vibration in the bedrock.

At Olkiluoto, the current passive monitoring includes the temporary installation of short period seismometers at the distance of 5–10 km from the suggested repository. The applicability of these sensors and the recording technique will be analysed in the following Chapter. Moreover, six short period accelerometers have been installed by the Operator (Posiva) at the repository site for rock mechanical evaluations. Also this data is available for the safeguards purposes.

6.4.2 Active seismic

Various active seismic methods could, in theory, be used to image the sub-surface. The refraction seismic surveying is applied to map the depth–to–bedrock profiles and to map seismic velocities at the rock surface. The common reflection seismic surveying, which directly produces profiles of the sub-surface, is not an effective technique in crystalline rock due to unpredictable reflectors in the rock mass and the rocky and uneven overburden, which provides poor acoustic coupling for the technique. However, reflection analysis has been applied to the Vertical Seismic Profiling (VSP) which is being carried out using surface sources and borehole receivers. This data are being used to establish detailed geological knowledge of reflecting features, proposed to present water-bearing fractures of zones of weak rock near the proposed repository volume. This method is of value in determining geological details of the site to be developed and will be used by the operator for that purpose. However, most probably it would not be capable of sufficient resolution at the depth being considered for the repository to be capable of detecting and identifying undeclared tunneling or cavities. The same conclusion can be made for the other seismic sounding techniques applied from the ground surface.

6.4.3 Ground Penetrating Radar (GPR)

The application of the Ground Penetrating Radar (GPR) is based on the reflectivity of the interfaces at which there is change in the permittivity in the subsurface. Owing to the different electrical properties of soil and rock; water, air and other filling material at fracture surfaces in the rock mass the method can be used to map these interfaces as reflectors.

Similar to the active seismic method, the GPR has been applied from the surface and from boreholes for rock characterisation purposes. The GPR method has reveal several fractured bedrock sections owing to the good reflectivity at conductive (sulphide-, graphite-, and water-) filled fracture surfaces near the ground surface or near the boreholes. The average fracture frequency is of the order of 1 fracture/m along the boreholes, and geological control is available only at those anomalies intersected by the borehole. Moreover, the borehole radar is blind to the very near zone around the borehole. There are also conductive mineral with the rock mass, making the interpretation even more complicated. In addition, the range of the method is limited from several tens of meters to 10 - 15 m owing to the high salinity of the ground water in the deep bedrock. The high conductivity of the water also tones down the anomalies. Owing to this limitation and the fuzzy number of reflectors the method is not applied systematically in the rock characterisation programme.

In safeguarding the repository tunnels, Ground Penetrating Radar (GPR) will record reflections also from cavities within a short distance of a rock face as reflectors. The potential role for GPR is in design information verification (DIV), in particular revealing undeclared cavities or tunnels. However, it should be noted that GPR performance will depend on the physical properties of the host rock and the radar equipment, antenna frequencies and operator-dependent recording parameters used. It will be obvious that a reflection originating from a void is difficult to be identified from a reflection originating from a geological boundary. However, repeated GPR surveys could be used for the detection of undeclared voids in different parts of the future repository and to provide confidence that no undeclared voids are in the vicinity. For the monitoring, a GPR baseline data set should be collected and stored for the further analysis during the excavation of the repository, since the reference is the geology with the sources of the anomalies around the declared repository design. During the monitoring and analysis of the anomalies the records should be compared owing to the equipment used and persons responsible for the operation, processing and interpretation of records. Therefore, there will be development tasks for the technique before it can be recommended to be used as a proven technique in safeguarding the Olkiluoto repository.

6.4.4 Electromagnetic and electrical methods

There are a variety of methods for measuring the electrical properties of the sub-surface. Electromagnetic and electrical methods may be used in site evaluation to determine conductivity at depth, which in turn is used to assist in the development of a hydrological model for the repository owing to variations in the groundwater salinity. Although electromagnetic/electrical techniques could be used for detecting both non-conducting areas such as open air-filled tunnels and conductors such as rails and electrical wires or the saline water-filled voids, these techniques cannot be thought to be practical for safeguards purposes.

7 Methodology and procedures for safeguards measures at Olkiluoto repository site

According to the recommendations for the pre-operational phase of the repository generated in the Programme for Development of Safeguards for Final Disposal of Spent Fuel in Geological Repositories, the role of geophysical methods, environmental sampling, and satellite and aerial surveillance techniques will become more prominent in the IAEA safeguards. Moreover, it is recommended to generate the baseline of natural conditions before the excavation work begins. Safeguards requirements should be integrated into the repository design at an early stage in order to establish functional, non-intrusive, and cost-effective safeguards measures.

The investigations for the site characterisation at Olkiluoto proceed to the underground phase in 2004. According to the site characterisation investigations carried out from the ground level and from boreholes during last 20 years, the natural conditions are documented and the design of the underground facilities is carried out by the implementer (Posiva 2003). The excavation of the underground rooms and tunnels for bedrock characterisation at repository site is scheduled to begin in 2004. Therefore, the preliminary excavation related procedures; i.e., the cleaning of the rock surface with the removal of vegetation and soil cover near the Onkalo begun in 2003.

The main task for safeguards is to observe the development of the underground space, which can be called as Design Information Verification, and the creation of the credible assurance of the absence of the unannounced activities near the repository site. The Finnish national system of safeguards will consist of field audits and review of the progress in tunneling works and site characterisation. The safeguards-related obligations will be focused on these procedures. Some additional information may be collected using independent surveillance or monitoring techniques. The national system will assist the IAEA to enable the efficient and cost-effective safeguards for the Olkiluoto repository site.

7.1 Monitoring of the Olkiluoto area for long-term safety assessment

The development of the Onkalo will be based on coordinated investigations, design and construction activities. Pilot holes will be drilled and cored along the tunnel profile as the excavation proceeds and investigations will be out for geological, rock mechanical, hydrogeological and hydrogeochemical characterisation. In addition, monitoring is planned at the ground surface, in boreholes drilled from ground surface, in boreholes drilled from Onkalo and in Onkalo itself. 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 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.

7.2 Remote sensing of the Olkiluoto site

The technology of satellite imagery is well proven and has been used by the military community for many years. There are a number of sensor systems available giving users the ability to remotely observe earth based objects in all weathers and conditions. From 1991 onwards, the IAEA recognised the potential of using commercially available satellite imagery to support their safeguards activities. A principal objective being to verify and monitor the activities at declared nuclear facilities.

The increase in the use of satellite imagery has resulted in several national programmes to construct and launch satellites equipped with a wide range of sensors and to subsequently make the imagery available. Therefore, there are a number of sources from which imagery can be obtained. The IAEA has used several suppliers in order to have independent and thus non-manipulated images for its unannounced surveillance and inspection procedures. Similarly, within the Finnish Support Programme the earth observation techniques are reviewed and “zero-point” imagery at Olkiluoto is processed in 2003, i.e., at the stage before of the scheduled construction of the underground facilities. The satellite imagery is related to the observation of the ground surface (Häme et al. 2004). Therefore, the method can be applied to indirectly to locate mining activities, owing to new installations, traffic routes and waste rock areas. Also changes in water tables or in vegetation can be observed as indicators of underground activities, but the excavated rock volumes can not be estimated at the scale of an undeclared room within the underground gallery.

Optical satellite data with sub-meter resolution is the best and possibly an adequate alternative in earth observation if there is flexibility in the selection of acquisition time. If more frequent image acquisition is desired the monitoring should involve using synthetic aperture radar (SAR) that can acquire imagery under all weather conditions during all seasons. Particularly in Finland and other northern and/or cloudy regions the significance of the SAR imaging is emphasized to ensure image acquisition from a desired instant of time. Present SAR instruments offer imagery with approximately ten meters resolution at best but not later than the year 2006 SAR data with a couple of meters resolution should be available.

It was considered important that the baseline data include the same data types that are possibly utilized later in continuous monitoring and in the possible emergency surveys. Therefore also SAR data from the Olkiluoto site has been ordered. Until January 2004 four SAR images of from the five ordered are available. Also, three different optical images are acquired for the baseline database. The best image type for close-up site monitoring is either the panchromatic image alone or a fusion of the panchromatic data of 0.6-meter resolution and multi-spectral data of 2.4-meter resolution (Figure 4). The practice will show whether inclusion of the multi-spectral data is worth the increased costs.

The SAR images matched with each other and with the topographic map generally well. In some cases the images suggest that the map, purchased to serve a reference, may have some inaccuracies. Use of the coordinate information in the SAR images resulted in an approximately 20-meter shift from the map after the geo-coding. The shift was corrected using manually selected tie points from the maps and images. The SAR data alone are rather difficult to interpret due to the speckle noise and due to low resolution. The major buildings have very high intensities and are thus striking in the image. Also some other objects with high conductivity are distinct. However, dull colours on land in the image that has been combined from the four original SAR images indicate that between the SAR image acquisitions there has been hardly any such changes in the Olkiluoto area that would have been detectable using SAR instrument (Figure 5).

7.3 Geophysical monitoring at Olkiluoto

A wide range of geophysical techniques are planned to be applied to generate raw data for the site characterization of Olkiluoto. The data will be interpreted for the geological characterization 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. However, the rock mechanical monitoring will give the most safeguards-relevant information. The excavation-introduced seismicity will be studied using a net work of micro-seismic stations at the investigation site. These seismic observations 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 implemeter, Posiva Oy. The interpretations are also reviewed by the national authority, STUK.

The Institute of Seismology operates a network of long-period seismic stations in Finland. The nearest station is located at the distance of 200 km to the northeast from the Olkiluoto site. However, the station together with the network is used for the seismicity analysis at Olkiluoto. Since the earthquake activity in the Precambrian rocks is very low, the seismic data reveal mainly seismic noise that can be also be related to diurnal activities and to construction activities (STUK 2003). These seismic patterns will improve when the new station at Laitila, only 50 km apart from the Olkiluoto site, will be installed.

Figure 4. Combination of QuickBird multi-spectral image sharpened with the panchromatic channel from the geographical location of Onkalo. This image (September 9, 2002) includes the near infrared spectral band, which causes light colour of broad-leaved tree forest.

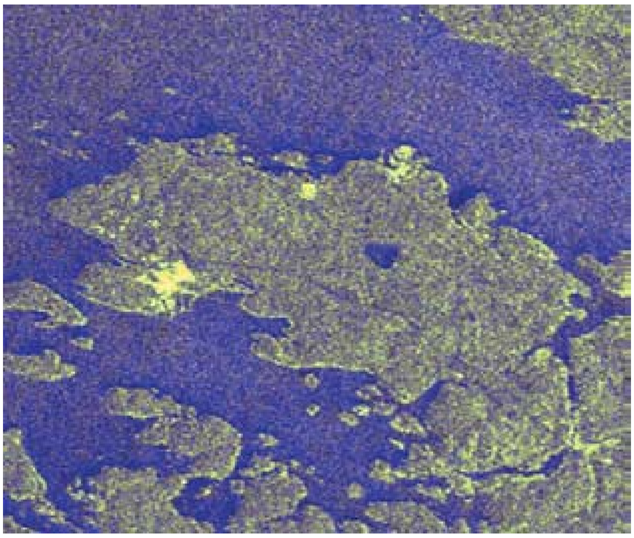

Figure 5. Combination of the four ASAR images from Olkiluoto environments. Colour codes: Red – temporal mean amplitude of four images; Green – mean spatial texture of four images; Blue – temporal variability between four images.

In addition, a temporary set of local short period seismic stations was set up by the Institute of Seismology around the Olkiluoto facilities in 2003. Two stations are located at different azimuths at a distance of approximately 5 km from the planned repository, and one station is referenced to one of the micro-seismic stations near the cored borehole OL1 at the geological site. At the stations there are Teledyne-Geotech S13 SP and Lennarz 3C seismometers with a sensitivity of 1630 Vs/m and 400 Vs/m, respectively. The data 100 samples/second and 120 dB dynamic range, 6–9 GB of HD space) are stored with DAS98 data loggers. The hard disks are changed bimonthly.

The first records present the noise level near the Olkiluoto site (Heikkinen & Tarvainen, 2003). It is worth to point out that the station at the site records the highest level of temporary noise, most probably introduced by the power plants and related activities including also traffic to the Olkiluoto harbour (Figure 6). The vibrations peaks at 6.1–6.6 Hz are due to the power plants. The reduced noise level before noon is due to maintenance work reported at the power plant. In the remote sensor at Kuivalahti, located 5 km to the northwest from the site, only traffic noise can be observed (Figure 7). The working hours with the peaks at the morning rush hours and lunch time can also recognised. The recording scheduled to continue over the starting point of the excavation works for the repository in mid-summer 2004. The records will be analysed for their safeguards-relevancy in 2004.

7.4 Radiological monitoring

The radioecological background monitoring at Olkiluoto is carried out by STUK since 1972, and environmental monitoring in 1977, one year before the operation of the NPPs begun. This monitoring gives a reasonable background, or baseline for comparisons while monitoring the chances introduced by the future operations in Olkiluoto or elsewhere in the world. The present baseline contains information related to the global fallout including the Chernobyl accident.

The underground tunnels will be monitored for operational health purposes; in particular, radon can be assumed to be present in the facilities. The procedures and isotopes to be monitored for safeguards were reviewed in 2003. However, the Safeguards-related radiological monitoring is not considered to be relevant before the movement of nuclear material is moved to the facility to be constructed. Before that time, a new site-specific baseline data can be acquired.

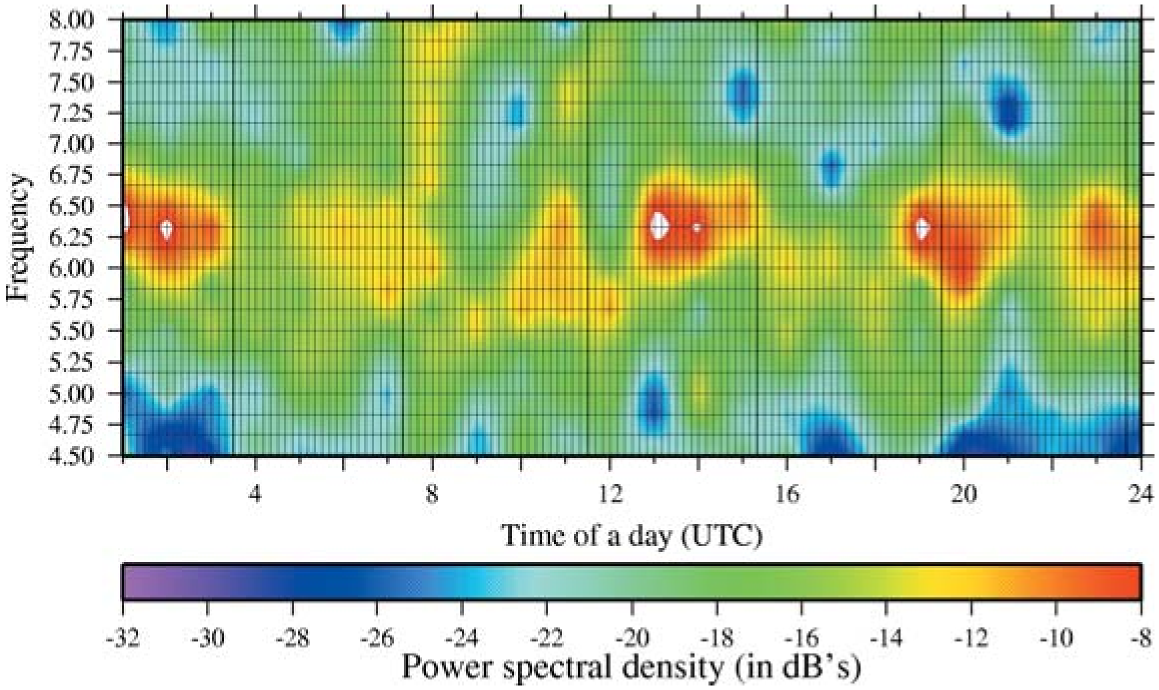

Figure 6. Daily noise level variations in Olkiluoto (OL1) on Monday August 25th 2003.

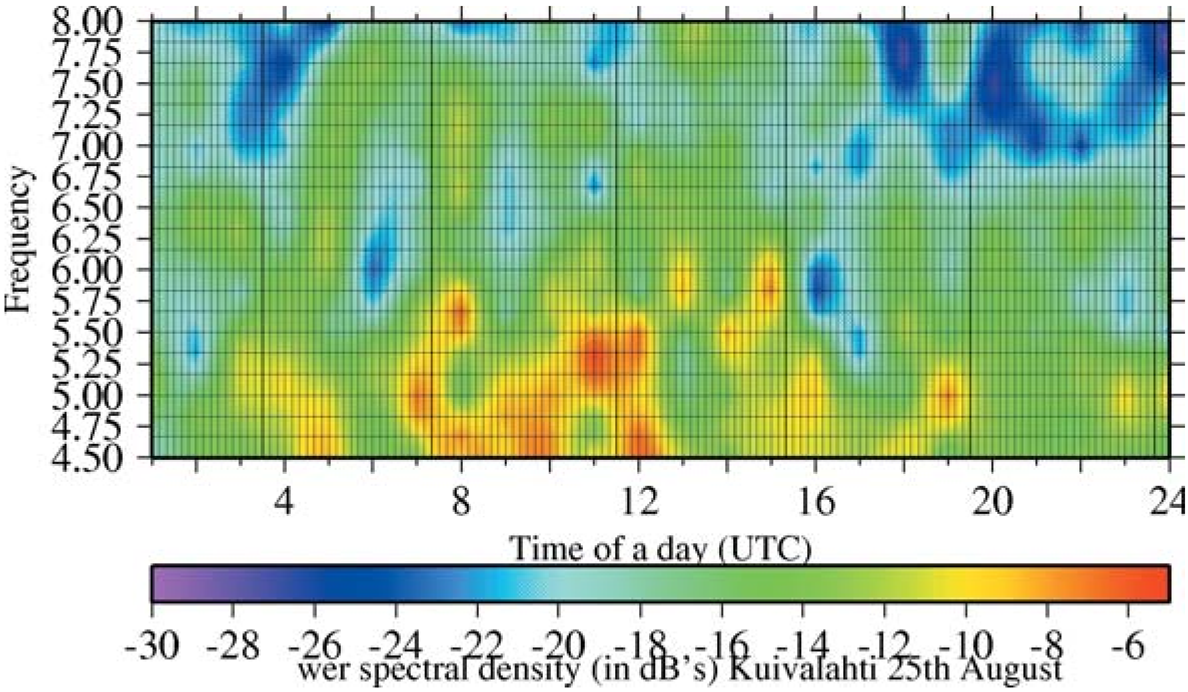

Figure 7. Daily noise level variations Kuivalahti 5 km part from Olkiluoto on Monday, August 25th 2003.

8 Summary

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 are proceeding to the underground phase in 2004 when the excavation of the tunnel system for bedrock characterisation at repository site begins. 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 safeguards approach for the pre-operational phase at Olkiluoto site is suggested. At this phase the main obligation is to be ensured about the absence of undeclared activities at or near the repository and during the excavation of the investigatory galleries the verification of the excavated rock space and its geometrical volume.

The Olkiluoto repository will be located in the 1800–1900 million year old crystalline rock. All underground excavation works is this hard rock must be carried out using drilling methods. Therefore, the safeguards-relevant monitoring can be focused on mining introduced vibration analysis and to mining-related activities. The passive seismic monitoring and remote sensing techniques are suggested for these purposes. Both methods give indications on the activities near or at the repository. In addition, the hydrological monitoring near the site will give signals as unexpected changes in water pressure or chemistry due to unknown openings in the rock volume. Earth observation techniques can also reveal phenomena related to mining and quarrying activities, owing to secondary phenomena, e.g., changes in water tables or mass transports, construction of buildings etc. However, these methods are insensitive to the amount of rock volume excavated or to the volume underground space developed.

The design information generation and verification for safeguards purposes should be 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. The verification of the progress in tunnelling should be 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.

Geophysical soundings at the site characterisation phase have shown that in the bedrock of Olkiluoto there are features that introduce anomalies in the measurements. The observation capabilities and the interpretation of the anomalies and their source location vary owing to the technology, parameters and operating personnel. Most of the anomalies are related to hydraulically and mechanically anomalous bedrock features. Densely fractured zones introduce the main anomalies to the present geophysical techniques. The mica gneiss at Olkiluoto contains fractures at the average spacing of 0.7–1.1 m. Most of these contain infillings that may be electrically conductive therefore observable as anomalies also beyond the reinforced tunnel wall, also the reinforcement itself will introduce anomalies. The future re-assessment of these observations using some future techniques may improve the geological knowledge about the site, but the safeguards-relevant procedures are, most likely, to be integrated with the construction procedures.

The pre-operational phase of the Olkiluoto repository should be efficiently used by the parties involved in safeguards. The applicability and reliability of the potential new techniques and the efficient practices must be developed and proven before their implementation as safeguards measures to be applied at the subsequent stages of the repository development. In addition, practical implementation of safeguards measures needs to be applied already before the first excavations and blasting operations and parallel to the underground gallery development. The national approach is based on three independent monitoring systems that are in parallel operation already one year before the excavation is scheduled.

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