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IMGS 2003 REPORT

The geological and structural characterization of the Olkiluoto site in a critical perspective

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In STUK this review process was co-ordinated by Kai Jakobsson

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Abstract

This report comments on aspects of Posiva's work relating to the interests of the IMGS (Investigations and Modelling of Geological Structures) Group who is concerned with the potential impact of the tectonic and geological setting of the Olkiluoto site, on the construction a deep repository for spent nuclear fuel. Since the Group's last report (IMGS 2002) a variety of relevant publications have been produced by Posiva. A number of issues have been identified in these documents relating to the procedure for updating the Bedrock model, factors influencing the location and layout of ONKALO, the mapping procedure planned for the access tunnel, the problem of oversimplification and uncertainties and the proposed extension of the repository. These are discussed in the present report.

Preface

Spent nuclear fuel from the Finnish nuclear power plants will, in accordance with the Nuclear Energy Act, be disposed of in domestic bedrock. The Finnish Government has made a decision in principle (the "Decision In Principle" by the Government on the 21th of December 2000 concerning Posiva Oy's application for the construction of a final disposal facility for spent nuclear fuel produced in Finland), which Parliament ratified in 2001, on the disposal facility to be located at Olkiluoto in the municipality of Eurajoki. The next milestones for the Research and Development program are attaining the maturity for the submittal of a construction license application in 2012.

Posiva has carried out field investigations in Olkiluoto since 1988 and the outcome of these investigations in essentially summarized in a structural bedrock model. The construction of Underground Rock Characterization Facility (URCF, known as ONKALO) in Olkiluoto is the final phase in the long sequence of the site selection work. Parts of the URCF are later be used as a part of the auxiliary space of the repository itself, if appropriate.

General guidelines and decisions on the regulatory aspects concerning the final disposal are given in STUK's Guides YVL 8.4 (STUK, 2001) and YVL 8.5 (STUK, 2002). Also the 'Decision in Principle' (DiP) contains (in its arguments) some general views on the repository itself, repository depth for example.

In STUK the review process, reported here, was co-ordinated by senior inspector Kai Jakobsson.

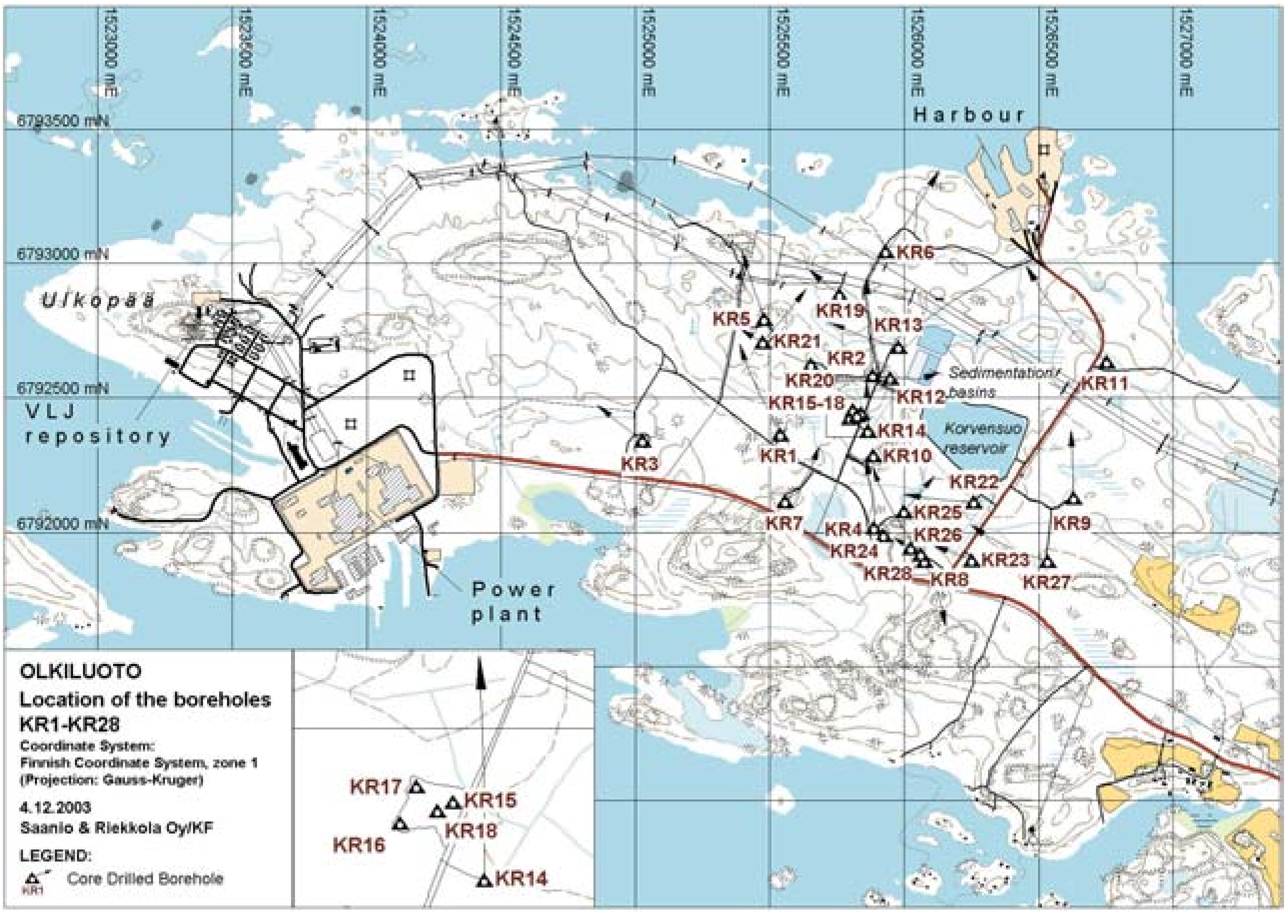

Figure 1. Location map showing the Island of Olkiluoto, the power plant and the cluster of borehole localities at the proposed repository site. Background map © National Land Survey of Finland, permission 168/MYY04.

Contents

1 Background of IMGS group

The support group for the Investigations and Modelling of Geological Structures (IMGS) is one of four support groups set up in the spring of 2002 by the Radiation and Nuclear Safety Authority (STUK) in connection with its regulatory activities related to the underground rock characterization facility to be constructed at Olkiluoto.

The four thematic STUK groups are;

- Investigations and modelling of geological structures.
- Geohydrological investigations.
- Hydrogeochemical investigations.
- Bedrock movement investigations (GPS and microseismic monitoring).

The interests and concerns of the IMGS Group are, in practice, divided into two main areas. The first relates to the geological modelling and investigation of the Olkiluoto area, the proposed site for the construction of a nuclear waste repository. This covers the approach used and the method adopted to study the site at Olkiluoto. The second and related area of interest relates to the planning of the ONKALO facility including the location of access ways, the preliminary design and the need for complimentary investigations with respect to the existing structural model.

The IMGS Group's working plans for the year 2003 included two meetings in Finland (August 20-22 in Espoo and November 6–7, 2003 Helsinki) in addition to a meeting and presentation at STUK's office in Helsinki (August 22nd, 2003), a review of reports submitted by Posiva, and the writing of a review report for STUK. In the request for an offer sent to the Group members, specific requirements were itemised. These included a study of the updated bedrock model of Olkiluoto and of the optional access ways.

The IMGS Group members are expected to evaluate the results of the investigations with respect to the structural model and to discuss and report their findings. The Group are grateful for the effort made by Posiva to ensure that key reports are available in English but regret that the timing of the delivery of the reports is still not well organised. Information often arrives too late for feedback from the IMGS Group (or STUK) to have any impact on decisions.

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2 Introduction

Over the year a variety of documents have become available. The present report presents issues of concern that have arisen during this period as a result of i) the study by the IMGS Group of the Posiva documents and ii) subsequent discussions at the meetings. The concerns discussed in this report relate to the following topics;

- The procedure for updating the Bedrock model.
- Factors influencing the location and layout of ONKALO.
- The mapping procedure planned for the access tunnel.
- The problem of oversimplification and uncertainties.
- The proposed extension of the repository.

A large amount of data on the geometry and properties of the rock mass at Olkiluoto are being generated relating to the proposed construction of a nuclear waste repository. It is important to ensure that these are integrated into the bedrock model in an efficient, objective and transparent manner. The report comments on this task and discusses the problems of 'model updating', particularly during periods of rapid accumulation of data such as will occur during the construction of the access tunnel to the ONKALO.

The report also considers the criteria used to determine i) the method and design of the access to ONKALO and ii) the repository location. The construction of the access tunnel has just begun and the characterization program and mapping procedure that will accompany this has been assessed. The proposed characterization programme is discussed and recommendations made which it is hoped will help maximize the rock characterization accompanying the construction.

The IMGS Group notes in the ONKALO (UCRP) report (Posiva 2003-03 Sept. version), that conclusions of STUK's review of Posiva's 2000 RDD program are presented and one point that was stressed and would facilitate STUK´s and the IMGS Group's work is that Posiva should develop a basic data accessibility plan in consultation with STUK in order to enable external review. Hopefully, this will be arranged in the near future.

The IMGS Group has not had the opportunity to study the 3 year RDD document (not delivered) nor the Strategy document (late delivered) even though the ramp tunnel had already been started. It expressed concern that Posiva should not generate a situation where it was too late for the Group's comments to be considered and implemented.

The IMGS Group felt that the late delivery and non delivery of some key reports meant that there was no time to assess the important issues raised in these documents which would require detailed study and consideration and which could impact very markedly on the programme of work at Olkiluoto.

In view of the above comments it is felt that Posiva should be asked to improve the delivery of their documents and to sharpen up their delivery procedure.

3 Updating of bedrock model

In the previous report of the IMGS Group (STUK-YTO-TR 196) the Group expressed concern regarding the procedure for updating the Site descriptive model (see below) and for the procedure for disseminating the updated model in a manner that would ensure that people working in different disciplines were made aware of these updates at the same time. These concerns persist and are discussed more fully in the following paragraphs.

3.1 Model updating procedure

In the ONKALO-UCRP report (Posiva 2003-03) it is noted that modelling;

- Is a continuous activity (new information becomes available all the time).
- That for model integration and consistency checks it is essential to define suitable Milestones, (data freezes), where different disciplines use all the data available at the same time.

The IMGS Group agrees with this statement and reiterates the questions posed in their previous report namely;

- Who collects and collates these data?
- When and how are the models updated?
- When and how are the subject specific models integrated into a Base Model?
- How do all the workers receive the updated model?

Two processes can be involved: i) The constant updating of the subject specific models (i.e. Geological, Geochemical, Hydrochemical and Rock Mechanical Models) as new data becomes available and ii) the integration of the subject specific models into a Site Descriptive Model.

In the ONKALO-UCRP report (Posiva 2003-03) it is stated that …"A specific 'modelling task-force' will be set up for the integration of the results of the modelling work in different disciplines."

It appears from this statement that no group or individual at present exists to oversee this task and the IMGS Group wonders how the data from the various disciplines have been integrated into the model up to now and when the proposed 'modelling task force' would be established.

3.2 Uniqueness of models – alternative models

A fundamental question raised at the IMGS Group's meeting with Posiva at STUK's offices in Helsinki (August 22nd, 2003) relates to the uniqueness of any model generated by the above procedure. The question posed was "Using the same data set is it likely that two investigators or two investigation teams, will produce two significantly different models?"

The IMGS Group notes that the construction of both types of models, the subject models and the site descriptive model, involves the integration of data and the interpretation of data and that the latter is likely to vary in some aspects from interpreter to interpreter and thus may lead to the production of different models. *Instead of one model there should be more conceptual models.* The IMGS Group concludes that the interpretation of structures by different workers will inevitably produce different models the accuracy of which will be very difficult to assess. It seems appropriate to attempt to quantify these differences i.e. to check the uniqueness of model by having more than one group analyse the data.

This problem of uniqueness also arises when the subject specific models are combined into a single model. Such integration often requires the correlation of interpretations (models) and not correlation of actual data – this is an integration of interpretations (all interpretations are basically based on the same model, i.e. the geological model).

Although Posiva acknowledged this problem at the meeting on the 22nd of August, the IMGS Group note that the production of alternative models (independent models) is not discussed in their reports.

3.3 Updating of models

In addition to the concerns discussed above relating to the lack of clarity regarding the way in which new data are integrated into the 'models' of the repository site as a whole, the IMGS Group notes that the updating and modification of the model for the ramp tunnel and ramp volume will need to occur rapidly in order to keep pace with the project as the tunnel develops. This will require a more rapid procedure than at present operates.

In this regard the Group was interested to note Posiva's comments on the model related to the construction of the ramp (Posiva 2003-03), which indicates clearly that they are aware of this problem. They state ..."Modelling will be updated several times, first during the selection of the access tunnel volume, then during the construction site investigation and finally when the tunnels and investigation drillings are completed within a particular volume."… They note that …"a faster, 'on-line' type method needs to be created to run parallel with the current type of long term data processing and interpretation scheme".

The IMGS Group is interested in the development of this method and hope that the discussion in section 5 of this report will be helpful in this regard.

3.4 Different scales of models

In addition to the different types of modelling noted above modelling will also occur on different scales. These are Regional (to semi-regional)-scale (100–10,000km^2), site-scale (3–4km^2) and local-scale (1–10^{-2}km^2). The Group would appreciate a figure showing the location of the different scales (model areas/volumes) and an early presentation of a method description of modelling rock distribution and structures on all scales.

The IMGS Group asks whether these scales are appropriate for the Olkiluoto region. The scales selected should reflect the dimensions of the objects and features that characterize the area; namely scale needed to understand the geological setting of the repository site, the scales needed to describe large scale and near-field groundwater flow and mass transport, the scales needed to describe and understand natural variation in geochemistry (especially hydrochemistry) and the influences caused by the repository (at all stages), and the scales (far-field and near-field) needed to describe tectonic stress relations and rock mechanical stability of the repository site (including heat transport and heat induced stress field), especially around the canister holes.

All the large scales do not coincide (constitute the same volume of rock) and this also holds for smaller scales. In the SKB site descriptive work, the hydrogeological modelling generally defines the scales. Description of geological bedrock terrains may need another scale; e.g. in the Olikiluto regional area there are huge intrusions of rapakivi granites and large-scale block fault controlled sedimentary basins with Jotnian sandstones.

Posiva should clearly describe what they consider to be the used model scales.

It is notable that the size (scale) of models is treated but not the resolution within the models. The relation between scale and resolution should be discussed and described for each model. When this is done the consistency between different scale models should be discussed.

In Posiva 2003-03 report it states that..."Local-scale models will be developed representing different sub-volumes within the rock volume represented by the site-scale model. …The following five sub-volumes for ONKALO may be modelled in varying detail:" These are;

- The access tunnel 0–300 m level.
- The shaft site.
- The access tunnel as a whole.
- The main level characterization tunnel area at c. 420m level.
- The lower excavated parts down to 520m depth.

The reason for this is not obvious. A uniform acquisition of data (with appropriate resolution) may be more accurate (easier to compare the character of sub-volumes) and may help to identify structures on which to focus and sample in the succeeding investigation of the site.

3.5 Potential problems

The IMGS Group identified two other questions relating to the modelling procedure that require addressing. These are;

- Is the decoupling of the subject specific models desirable?
- Where is the quality of data described?

Whilst understanding the logic behind the development of subject specific models the IMGS Group is concerned that this decoupling of the subjects may not be advisable. They consider that the geological model is the fundament or at least will have a central role in the construction of the geochemical, hydrogeological and rock mechanics models.

The Group was concerned to learn that the hydro-geochemical model had been considered independently from the geological model. It questions whether it is sensible to do this when the hydrology of the peninsula is so clearly controlled by the geological structures.

Posiva are clearly aware of this problem and state in report Posiva 2003-03 that …"Even if a discipline model itself can be compiled independent of the geological model, as is the case for the hydro-geochemical model, analysing the result with regard to the geological model will be beneficial for the development of both models."

3.5.1 Quality of data.

In the report on Strategy for Construction and Investigation Planning (Posiva WR 2003-28) the problems of Data processing, interpretation and modelling are discussed. The Group could find no comment concerning the quality of the data used in the various stages of data processing and modelling. If Posiva and their consultants are interested in the quality of their modelling there must clarity regarding the accuracy, error limits and detection limits of their primary data.

In the ONKALO-UCRP report (Posiva 2003-03) it is noted that …"the main purpose of data processing and interpretation is to assess the quality of the data and to convert the large amount of raw measurement data into a manageable and meaningful form for use."… The IMGS Group notes that there is the risk of introducing distorted data sets (especially if different types of indexes are introduced e.g. the fracture zone index used by SKB) and suggest that some sort of 'intelligent' data tool should be used. In addition the method of data processing should be recorded and the raw data always remain available.

3.6 Example of complimentary data acquisition – mapping the rock head

It was noted that within the surface based investigation programme, mapping of the rock head is missing and the IMGS Group wonders whether it will be presented when the distribution and character of Quaternary deposits is reported. Such information may locate the outcropping of fracture zones and indicate the location of late block movements. It was good to read that there will be a "special emphasis to study fault – faulting". Such a study will require a programme.

4 Factors influencing the location and layout of ONKALO

4.1 Location of the repository

The criteria used to select the location and layout of the potential repository site and to determine its layout are within the concern of the IMGS Group. They discuss this in their report (IMGS 2002 report) where two points are highlighted;

- Regarding the location of the repository site, the IMGS Group would like to have seen several models of certain selected areas drawn using different assumptions and would like to understand the arguments used in the selection of the current site.
- The IMGS Group was informed that a number of alternative layouts were considered for ONKALO, some involving others tunnels and shafts. It would be interesting to see where these alternative layouts were positioned within the proposed repository volume and the criteria used to select the chosen scheme.

4.1.1 Location of the repository site

IMGS Group members discussed with a POSIVA representative the rational behind POSIVA's decision to select the current ONKALO layout from the various layouts that had been considered. The arguments presented were that a huge risk, difficult to assess, would be associated with putting ONKALO together with its access tunnel and shaft, in an 'unmapped' area on the Olkiluoto peninsula. The IMGS Group found this logic unacceptable and it was agreed that POSIVA should be questioned on this at the meeting at STUK's office's (August 22nd, 2003) when the associated problem of the limited geological exploration of the areas immediately surrounding the proposed repository site should also be raised. In addition the Group felt that the justification for the selection of the chosen layout and the rejection of the others should be presented in reports.

In addition to the Group's concern regarding the lack of clarity of the selection process of the repository site noted in the preceding paragraph, they were also surprised to read in report Posiva WR 2003-28 on 'Strategy for Construction and Investigation planning' that: "The systematic site identification survey and the following site characterisation programme have shown that the Finnish bedrock is suitable for the construction of a deep disposal for the spent fuel."

As far as the IMGS Group is aware this has never been proved to be generally true in Finnish bedrock, but is still conditional, depending on the future site characterisation results. They are interested to know who made this statement and when and where it was made. An extensive and ongoing investigation is being carried out at Olkiluoto to determine the suitability of the site for the construction of a repository for spent nuclear fuel. Based on this research and characterization programme Posiva hope to present a convincing case to demonstrate site suitability that will lead to the granting of a construction licence.

4.1.2 Alternative layouts of access tunnels and shafts of ONKALO

The IMGS Group had been informed that a number of alternatives had been considered in the selection of the proposed access routes to the ONKALO site repository volume. In ONKALO-UCRP report (Posiva WR 2003-3) the location of the access tunnel(s) is discussed and it is noted that …"Alternative locations for the tunnel portals at Olkiluoto have been explored."

The IMGS Group would be interested in these alternatives and in understanding the rational used in choosing the final layout.

They have asked for this to be presented, but to date this has not been satisfactorily done. They had obtained of a report entitled 'Evaluation of access routes to the ONKALO underground Characterization facility' (Posiva WR 2003-58), but only two alternatives are considered and illustrated in this namely two shafts, and one shaft and one tunnel. By the end of 2003 the group received a report (Posiva WR 2003-26), where the exclusion of some alternatives was explained, mainly based on the risk of constructing tunnels in an unknown bedrock area. The alternatives are not compared against the bedrock model.

The IMGS Group would like to know;

- How many models were considered?
- How they were reduced to these two?
- How the geometries and locations of these two models were decided upon?

In the introduction to the report ONKALO-UCRP (Posiva 2003-03) it states that the report …"describes the Underground Characterization & Research Programme to be carried out at the ONKALO underground research facility"…The IMGS Group wondered to what extent its own report (STUK-YTO-TR 196) had been taken into consideration when preparing the programme. The latter report is briefly discussed in the Posiva 2003-03 report where it is noted that…" In STUK's opinion the access route to ONKALO should be designed so that they will not be above the rock volume meant for disposal, nor in their vicinity."…This argument is countered by noting that; …"most of the rock volumes outside the high transmissivity zones (i.e. outside the proposed repository volume defined by these zones) would also be suitable for repository tunnels, which implies that the tunnels and shafts will necessarily be located in rock volumes that are potentially suitable for disposal as well."

The IMGS Group was not impressed by this argument. They had expressed a concern that the block of rock identified for the repository and defined by the high transmissivity zones, be disturbed as little as possible by the construction of the access tunnels and shafts. The suggestion, that by keeping the access tunnels and shafts away from the repository area as much as possible so as to protect its integrity, is valid and to argue that in so doing areas outside the repository volume may be rendered unsuitable for any possible extension of the repository site is of second order importance when compared to the possible damage to the repository caused by the invasion of tunnels and shafts into this volume.

The IMGS Group considered that report Posiva 2003-03 reads well and seemed focused but was concerned that little effort had gone into exploring the area surrounding the proposed repository site in order to assess its properties and suitability for storage. The Group had previously expressed concern at the apparent lack of study of the Olkiluoto peninsula outside the proposed repository area. The group noted that in section 4.2.2 of Posiva's report it is stated that in addition to the surface based investigations linked to the construction of ONKALO, …"investigations on the outskirts of the possible repository area and studies to determine site specific geological features to examine additional areas of interest will be carried out." (Posiva 2003-03). The Group looks forward to receiving more details of these two projects.

The IMGS Group considered the advantages of locating the access tunnel in areas which are not yet well characterized e.g. areas located in the western or eastern part of the Olkiluoto site. The advantage of this would be the gain of detailed information of such areas. However, Posiva consider the risk of these locations too high, despite the fact that the rock would be injected with grout before being excavated.

4.2 Policy on the disturbance of potential Repository rock

The IMGS Group noted that in the Strategy document (Posiva WR 2003-28) and also in ONKALO-UCRP report (Posiva 2003-03) the policy is not to disturb the repository volume. Posiva states that ..."the characterization programme must not jeopardise the use of potentially useful volumes of rock that would otherwise have been suitable for the location of parts of the repository."... However, as noted earlier, when the Group suggested designing the access tunnels and shafts outside the proposed repository area in such a way as to minimize the disturbance of the rock identified as the repository volume, Posiva rejected this. Their current plans are to drive the access shaft and the tunnel through the planned repository volume.

The Group questions whether it is necessary to position ONKALO in the middle of a more or less well defined volume of 'sound rock', the proposed repository volume. They note that if Posiva puncture the most central part of the repository block right at the beginning of the construction work, there is a strong possibility that this would adversely affect the quality of the repository.

There is some confusion regarding Posiva's attitude to 'disturbing the rock mass of the potential repository'. The Group note that Posiva are reluctant to disturb (puncture) the area surrounding the proposed repository volume because of its potential use in expanding the area of the repository and yet are happy to drive both the access shaft and tunnel through the proposed repository volume. This apparent inconsistency requires clarification.

5 Comments on the mapping procedure planning for the access tunnel

The construction of the Portal to the access tunnel to ONKALO has already begun and the IMGS Group is concerned that agreed procedures are in place to ensure the correct exploration and characterization of the rock mass accompanies this work.

5.1 Types of boreholes

Different types of boreholes are drilled during the construction of ONKALO and its access tunnel and shaft, namely;

- Characterization holes, cored.
- Pilot holes, will be drilled within the profile of the tunnel, cored.
- Probe holes, will be typically 5–20m long, not cored.

These will be drilled to locate water charged structures that intersect the proposed tunnel path and which were detected by the pilot holes. The tunnel will be protected from these structures by grouting using the probe holes as injection sites. In theory the orientation, extent and position of the planar, water charged, zones of weakness could be determined if they are intersected by several probe holes. The position of the zone of weakness along the probe holes can be detected as it offers a lower resistance to drilling than the surrounding rock.

It is planned to drill 4 probe holes continuously along the trace of the access tunnel and have overlapping sections of approximately 5m between each run of probe holes.

5.2 Sub-surface and borehole mapping procedure proposed by POSIVA

The Group considered the investigations that POSIVA plan to carry out in the access tunnel during construction. It notes that the drilling of a pilot borehole was only planned for the stretches of the tunnel where the R structures, (planar, water conductive zones), were likely to be encountered on the basis of the surface and borehole mapping.

5.3 Sub-surface and borehole mapping procedure proposed by the IMGS Group

5.3.1 Introduction

The IMGS Group considered how best to;

- Evaluate the risk of encountering a 'danger zone' that was not predicted.
- Assess whether there should be a continuous pilot hole drilled.

The Group considers that a similar plan might be applied to the construction of the shaft, i.e. to predict the occurrence of R structures that would intersect the pilot hole of the shaft and also to use the shaft probe holes to test for unpredicted zones.

The Group would like to know if the investigation program in the shaft borehole will be similar to that in the other cored boreholes.

Because of the limited data base the Group accepts that the access tunnel and shaft are likely to intersect structures which are 'unpredictable' in their location and orientation. It notes that even though they are 'unpredicted' they would nevertheless be 'expected'.

In order to characterize these structures when they are encountered the following strategy is suggested.

5.3.2 Characterization strategy

The Group thought that it might not be necessary to drill a continuous pilot hole near the surface and suggest that the surface and borehole data should be used to predict the position of the R structures along the tunnel. If the predictions proved accurate then it could be argued that a continuous pilot hole would not be necessary until the tunnel reached depths where the extrapolation of the available data became unreliable or at depth below 300m. When the fracture zone is located by the pilot hole, extra characterization holes should be drilled to two or more sites in the zone and fluid head measurements made. The tunnel should then be advanced to the fracture zone and the effect on the fluid pressure caused by the intersection of the zone with the tunnel recorded.

The Group also suggestes that the same procedure be followed for fracture zones which, on the basis of surface and borehole data, were expected and predicted. The reticence to explore these predicted zones with 76 mm diameter characterization holes for fear of disturbing the rock volume is not valid when a tunnel of considerably greater diameter is being driven through the rock.

It was noted that the pilot holes are only used for identifying water conductive fracture zones, and core (rock) and water sampling (Posiva 2003-03). No geophysical data or fluid pressure values are collected. They can therefore not be called characterization holes. Nevertheless it was noted that the pilot and probe holes can be used to indicate the resistance to drilling which will be related to rock properties either intrinsic (rock type) or induced (fracture zone).

The IMGS Group recommend that more use should be made of the pilot holes. In addition to core logging and the monitoring of water it would be useful to carry out geophysical studies as well. This upgrading of the analysis of the pilot holes will give a better understanding of the fractured rock mass which will be helpful later in the deeper parts of the repository and repository tunnels where detailed knowledge of the structure is low. For example, tracer studies could be carried out on the fracture zones detected to check the validity of the geometric model and its interconnectivity. It is noted however that flow through fracture networks is mainly controlled by channels. It follows that even if the tracer studies show no apparent flow it is still possible that the zones might be connected.

The Group concludes that there should be a more focused treatment of the data coming from the tunnelling process so that the improvement in the understanding of the zones of high fluid conductivity be maximised.

In addition it is recommended that the drilling team should have a plan for coping with the possibility of high water pressure in the boreholes. This is important because of the risk to the drillers, their equipment and the environment.

5.3.3 Extent of fracture zones

The IMGS Group considers the diagram of a drill hole which showed the fracture zones marked along it as 100m radii discs. Obviously, several fracture zones had been filtered out and the Group wonders what criteria were used to determine which zones should be ignored. It would also like clarification regarding Posiva's definition of 'Minor Fracture Zones' and how these differ from 'Major Fracture Zones'. It was noted that there had been a considerable modification of certain fracture clusters, which in the latest model version (2003/1) had been divided into two sub-horizontal zones (i.e. R20A and R20B) separated by approximately 30m. They will be obliquely penetrated by the access tunnel and the Group considers that it would be interesting to determine whether these are two separate zones as assumed or whether they are hydraulically linked which would indicate that they were not.

5.3.4 Characterization procedure

In considering the problem of improving the characterization of the access tunnel the IMGS Group looked at a document relating to the 'Establishing baseline conditions and monitoring during construction of the Olkiluoto URCF access ramp (Posiva 2002-07). They discussed the problems of Monitoring and noted that national demands are different in different countries. They point out that monitoring data is essential for making decisions as well as reassuring society at large and draw attention to the rational behind monitoring. These include the following;

- To provide information for making management decisions in the stepwise programme of repository construction, operation and closure.
- To strengthen the understanding of some aspects of system behaviour used in developing the safety case for the repository and to allow further testing of models predicting these aspects.

- To provide information to give society at large the confidence to take decisions on the major stages of the repository development programme and to strengthen confidence for as long as society requires that the repository is having no undesirable impact on human health and the environment.

More specifically the IMGS Group considers that a good geometrical model of the tunnel profile is important and that when recording geo-scientific data the precise location of observations is essential. Continuous laser scanning of the tunnel rock wall was discussed and it was noted that such data could be combined with (draped over) photographic data (digital photos or video) and this would enhance the understanding of the recorded data and the description of the bedrock character.

The procedure of tunnel mapping is presented in Posiva report 2003-03, where it states that it is proposed to map the tunnel in detail. However, the Group feels that the time allocated for this process (Tunnel face mapping, 0.5–2h (i.e. 70–18m²/h) & Window mapping of the walls & roof (24–32m²/h)) may be too short. It is planned to record an impressive number of parameters and the Group is concerned that sufficient time be allocated to allow the mapping to be complete. They recommend that a 'Method description' for tunnel mapping be presented.

The Group suggests that perhaps Posiva could consider the techniques used for tunnel mapping at Äspö carried out by SKB and in addition consider the use of Laser instruments.

5.3.5 Who should oversee the characterization procedure?

The IMGS Group considered the report entitled 'Strategy for Construction and Investigation Planning' (Posiva WR 2003-28) a crucial document. However, the report have been overseen by Posiva and some concern was expressed that, based on the authorship, this appears not to have been the case. The Group is unsure whether the 'construction strategy' was steered by Posiva's consultants or if it represents Posiva's own strategy for the final disposal of the spent nuclear fuel.

With regard to this point the Group notes that in some reports, e.g. 'Host rock classification Phase 2, Posiva WR 2003-04', it is stated that the views expressed are those of the authors' (i.e. not necessarily those of Posiva). However, in report Posiva WR 2003–28, which is authored primarily by non-Posiva people, no such disclaimer appears implying that Posiva agree with the content and conclusions. The Group recommend that STUK discuss with Posiva its concern regarding Posiva's input into this seminal document, which defines the strategic procedures for the construction of ONKALO.

The Group also has concerns regarding the investigation procedure involving the pilot and probe holes and the characterization of the rock mass as the access tunnel advances.

The Group argues that this procedure should not be run by the team constructing the tunnel but should be overseen closely by Posiva. They should insist on the collection of the data necessary to locate the potentially dangerous fracture zones, make sure that they are characterized and recorded, and oversee the grouting. They suggest that an *agreed procedure* should be embedded in the contract of the type;

- 4 probe holes to be drilled every 25m.
- An evaluation of the results.
- The injection of a grout curtain when needed.
- The drilling of pilot holes where needed.

This is critical and should be carried out (overseen) by Posiva.

The Group asks how STUK planned to follow the project (run by Posiva) and oversee and influence the construction of the access tunnel. They recommend that STUK have a clear understanding (mandate) that will enable them to intervene when necessary, e.g. if something unforeseen is encountered.

5.3.6 Model updating

The Group has expressed concern regarding the way in which new data are integrated into the 'model' of the repository site as a whole and note that the updating and modification of the model for the ramp tunnel and ramp volume will need to occur rapidly in order to keep pace with the project as the tunnel develops. This will require a more rapid procedure than at present operates.

In this regard the IMGS Group was interested to note Posiva's comments on the model related to the construction of the ramp (Posiva 2003-03), which indicates clearly that Posiva are aware of this problem. They state “Modelling will be updated several times, first during the selection of the access tunnel volume, then during the construction site investigation and finally when the tunnels and investigation drillings are completed within a particular volume.” The group is interested to know the justifications of the ‘final’ updated model version before the excavation starts that presents Posiva’s best estimate of the prevailing bedrock conditions.

Posiva note that “a faster, ‘on-line’ type method needs to be created to run parallel with the current type of long term data processing and interpretation scheme. This means that the drilling results and inferred geological estimates are processed as they are received.” “…modelling must support supplementary planning and changes in construction when these are expected. The planning and preparation of construction requires that the results are assessed within a week or a month.” The problem of ‘Model updating’ is addressed in report Posiva 2003-03. The Group is interested in this ‘faster method’ and look forward to receiving details.

5.3.7 Timetable

The IMGS Group considers that the timetable for the program of work linked to the construction of ONKALO is still too optimistic. It points out that the structures are likely to be more complex than envisaged and that ONKALO is being built in the central portion of an extensive repository site. The Group argues that there must be a policy for dealing with problems encountered in the repository galleries.

Posiva’s planned timetable for the excavation of the access tunnel, as presented for the group, indicates that the construction work start already in July 2004; It was noted that the IMGS Group will need to get feedback from Posiva on the missing reports before that in order to have any possibility of influencing the procedure.

The Group expressed concern that the Strategy for Construction document (Posiva WR 2003-28) which has just become available needs considering and commenting on very rapidly because of the stringent timetable of the organisation of the construction of the access tunnel (outlined above).

5.3.8 Conclusions

In the report Posiva 2003-03 (Onkalo Underground Characterization and Research Programme) it states that one of the purposes of the access tunnels is ...“to provide an opportunity to explore the potential host rock volume in more detail.”

The IMGS Group notes that the construction of the access tunnel should not just be used to explore the character of the near-field of the repository but it should also be a part or the learning and planning process in characterizing the bedrock and should be used to achieve skills in both indirect and direct characterization of bedrock features. It would be possible to learn to recognise the first indications of a feature (e.g. borehole characteristics, seismic and radar indications) and what its actual appearance is (i.e. observed when it is crossed by, e.g. a tunnel). In order to gain this insight a continuous trace of cored drilled pilot boreholes is essential.

The early recognition of structures will enable them to be stabilized by grouting and will also impact on workers safety. However, the grouting plume created around the tunnel may introduce a large volume of artificial fracture fills and also influence the groundwater conditions in the bedrock (e.g. flow paths and chemistry). A good control of the injection of work is important as it gives information about the fracture system. Such information should be used in a continuous updating of the 3D geological model (“refine as you go”). For this reason detailed mapping of fractures is important.

The IMGS Group wonders whether there would be any stops/breaks for the evaluation of the applied excavation techniques and geoscientific programme.

A clear strategy is required for the mapping, characterization and modelling of the rock volume during the construction of the shaft and access tunnel linked to ONKALO. This will need an agreed procedure. It is suggested that Posiva’s model of the tunnel and the surrounding rock should be updated with information from the various groups working on aspects of the tunnel programme and that these groups be familiar with the model and its constant updating. The groups would include STUK, the Geological Survey, the Technical University, the Radiochemical Institute, the contractors etc. Clearly such a programme would require managing, as well.

In summary the IMGS Group's main concerns are that the tunnelling process provides the appropriate characterization of the rock mass and that the strategy of exploratory drill holes (both pilot and probe holes) be controlled by Posiva and not by the Contractors.

6 Oversimplification and uncertainties

As a result of a variety of factors including lack of data and natural variations in orientation and extent of fractures and fracture zones there are uncertainties linked to the various models generated to represent the repository area. Some of these uncertainties have been identified by the IMGS Group and are discussed below. They can be listed under the following headings;

- Fracture Characterization uncertainties and problems.
- R-structure uncertainties.
- Uncertainties regarding the number of fractures.
- Foliation: its effect on fracture orientation and repository layout.
- Disturbance analysis.

6.1 Fracture Characterization uncertainties and problems

The IMGS Group note that Posiva/Fintact has used a well-established fracture identification programme (see Posiva WR 2001-32) and that this method requires the determination of two parameters;

- Fracture density.
- Principal Component Analysis (PCA).

Fracture density is calculated by recording all identified fractures in the core. When the density equals or exceeds 10fractures/m, a 'fracture zone' is recorded and when equal or less than 7 fractures/m 'Intact rock' is recorded. In Posiva WR 2002-36 report on 'Host rock classification', it notes that the average facture density is 3 fractures/m and that densities of 7+ are termed 'Fracture zones'.

Principal Component Analysis (PCA) involves the statistical combination of 5 parameters (see Korkealaakso et al.1994);

- Rock resistivity.
- Gamma-gamma.
- Hydraulic conductivity.
- Fracture frequency.
- Radar reflections.

What is considered to be a significant fracture zone in terms of its hydraulic conductivity (Posiva WR 2002-36). The structures referred to are the fracture zones bounding the investigation site (in the Olkiluoto case such structures are located far outside of the actual site – regarding deposition tunnels) and structures with a transmissivity of $<5 \cdot 10^{-5}$ m²/s.

To date these two parameters (i.e. fracture density and hydraulic conductivity) have been used to define fracture zones. However, it states that …"a new system for classification of fracture zones will be developed in the Host rock classification project" (Posiva WR 2003-04). The Group asks whether this implies that the present structure model will be based on a different classification system to that that will be used in the tunnel mapping.

6.2 R-structure uncertainties

The IMGS Group has considered the way in which Posiva have built up their model of R-structures i.e. planar zones of weakness and high conductivity in the Olkiluoto Peninsula. The process, based on surface mapping and boreholes data, has involved 3 versions. The first is based on surface mapping from the 1980s and the analysis of aerial photographs. It shows 26 continuous planar features intersecting the repository volume and each other. The second version, the result of a more extensive database, shows the boreholes with the fracture zones marked along them as discs.

Although this representation is not as visually impressive as the first version it contains more information and acknowledges the fact that the accuracy with which the orientation of the fracture zones are known is low. The Group notes from the abstract of the Structural Model 2003/1 (Posiva WR 2003-43), that most of the 145 structures only intersect one borehole. Only 19 are extrapolated from one borehole to another or from a borehole to the surface and it is pointed out in the appendix of the report that the accuracy with which the dip and dip direction of the structures are known precludes extensive extrapolation.

The rational behind the simplification of the R-structures and their array is presented in report Posiva 2003-06 under the heading 'Fracture zone geometry' where it states;..."The modelled bedrock volume is conceptually divided into several hydraulic units: planar fracture zones (the parts of the bedrock with a high fracture density and a greater ability to conduct water) and sparsely fractured rock between the zones (the remaining part of the bedrock in which the fracture density and thus conductivity are low)". The geometry of the fracture zones is based on the conceptual bedrock model version 2001/2 (Posiva WR 2002-46) which includes 77 local R-zones.

As the group was informed, most of the zones in the latest bedrock model have been represented as discs located along the borehole in which they have been observed. The discs, with a constant radius of 100m, do not often intersect other zones so they do not constitute important flow routes either. Thus from the point of view of site-scale modelling of ground water flow, such discs are irrelevant.

The bedrock model version 2001/2 was revised and simplified, as was done in 1998 for previous ground water flow analyses of the Olkiluoto site (Posiva WR PATU-98-12), by ignoring the discs and zones with small extensions and low transmissivity, extending some zones to the boundaries of the model volume and joining together zones located very close to each other. Consequently, in addition to 7 regional zones, the bedrock model employed in this study contains 34 local R-zones. For the sake of simplicity all zones are assumed to be 10m wide in the geohydrological model.

Thus the latest geohydrological model characterises the proposed ONKALO volume with only 7R structures (R7, R19A, R19B, R20, R21, R24, R56, Posiva 2003-06). This seems to be due to the fact that the fracture zones are represented as discs on the boreholes with radii of 100m. This assumption is crucial in determining the effect of the R structures on the hydraulic properties of the proposed repository site. As a result of this constraint it is concluded that they do not extend sufficiently far to intersect each other and therefore do not constitute important flow routes. Consequently, from the point of view of site-scale modelling of ground water flow, the fracture zones (i.e. R-structures) represented by these discs are irrelevant.

The IMGS Group considers that the procedure for representing the structures as 100m radius discs and not extrapolating them beyond this limit is likely to result in a significant underestimation of the number of intersections of these structures and hence the connectivity and conductivity of the resulting fracture network. This they argue will result in an unacceptable oversimplification of the structural model. The rationale used for constraining the structures to 100m radius discs needs clarification (Fig. 2).

The IMGS Group notes that in the Baseline

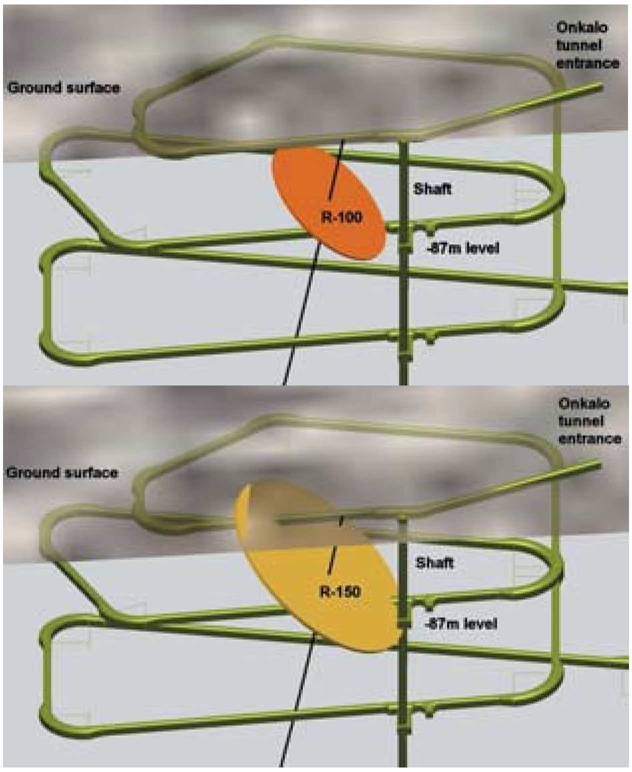

Figure 2. Sensitivity to a moderate increase in diameter of zone detected in a borehole (KR04, blue). Consequences for likelihood of intersecting structures in planned underground construction (in green: ONKALO tunnels and shaft): A. Posiva's standard 100m dia structure (R-100, orange), and B. redimensioned 150m dia structure (R-150).

report (Posiva 2003-02) which is essentially the summary of 20 years of geological study, the fracture zones are classified on a scale of 0–5 and it is recognised that the dip and dip direction values are also given to the nearest 10°. They feel that the limited accuracy of these data will significantly influence the accuracy of the models. In the same report it is noted that…"A few boreholes (28 at the moment) and the large distance between them create one of the main uncertainty aspects for all interpretations. A modelling of the Olkiluoto site, especially the continuation of geological features, like lithological units or R-structures, contains large uncertainties." This uncertainty is also reflected in the Posiva WR 2002-36 report where it states that …"There are as yet insufficient data available from the site investigations to make categorical statements as to actual geometric form of the structures."…

The constraints on the lateral extent of the fracture zones discussed above are likely to lead to an underestimation of their intersections and the Group is concerned that the resulting fracture network, which is assumed to control the movement of fluids through the volume, will be a dramatic and unrealistic oversimplification.

The Group notes that there are many different ways of linking the fracture zone indications in adjacent boreholes and that it is difficult to determine which belong to same zones. They note that the conductivity might also be a good guide to the extent of the fracture zone and may allow the diameter of the discs tied to the holes to be more realistically quantified. They suggest that one way would be to classify and compare their hydraulic conductivity.

6.3 Uncertainties regarding the number of fractures

The Group notes that in (Posiva WR 2001-32) it is stated that only approximately 50% of the fractures have been found. The Group wonder how this fact is integrated into the models. They point out that this means that the water inflow estimates into ONKALO given in Posiva 2003-06, will represent approximately 50% of the actual volume that will occur.

6.4 Foliation: its effect on fracture orientation and repository layout

The rocks of the Olkiluoto Peninsula contain a tectonically induced and during metamorphism originated foliation(s) which is(are) likely to impact on a variety of parameters including stress and fracture orientation. It should therefore be considered in the planning of the repository layout. The term is defined in the 'Host rock classification' document 'Phase 2' (Posiva 2003-4) which considers rock properties. The Group also considered the definition of foliation according to the IUGS sub-commission on the systematics of metamorphic rocks, namely "Any repetitively occurring or penetrative planar feature in a rock body."

Posiva notes that …"The majority of the rock mass at Olkiluoto contains a foliation (the Group notes that there is generally more that one), so it will not be possible to avoid it when locating of the repository." Group felt that certain fractures, particularly those whose orientation where at a low angle to the foliation, would be more constrained by the fabric.

The Group notes that, as acknowledged by Posiva, a number of structures will exist that has not yet been recognised and that as a result the reliability of is variable in the model volume (due to inhomogeneous data acquisition – borehole distribution and orientations). They note that in Phase 1 of the 'Host rock classification' (Posiva WR 2002-36) Posiva conclude that…"Additional structures (not included in the model) may be significant in determining repository location"… and it also states that…"No specific account was taken of possible long-term safety implications in determining the orientation of the deposition tunnels"… However, it is noticed (Posiva 2002-05) that strength and deformation properties of the rock were found to be noticeably dependent on the schisosity.

6.5 Disturbance analysis

The impact of the construction and running of ONKALO on the hydrological behaviour of the repository volume is considered in report Posiva 2003-06 where an attempt is made to assess the likely disturbances.

As was pointed out in above, the constraints imposed on the lateral extent of the fracture zones is likely to lead to an underestimation of their intersections. It was argued that this would result in the fracture network, (which is assumed to control the movement of fluids through the rock volume), being unrealistic and oversimplified.

It follows from this that in the bedrock model used in the disturbance analysis, many of the structures are ignored and most of the repository volume appears intact. The IMGS Group therefore questions the significance of the flow paths predicted for this model (Posiva 2003-06) and consider it to be inappropriate to act as the basis of the monitoring programme. This problem needs to be addressed.

Another problem linked to the construction of ONKALO is the ingress and raising of the level of the saline water. Concern was expressed that the influx of fluids into the workings, predicted during the construction of ONKALO and the related access shaft and tunnel, would not be representative of the influx into the final repository which would contain many more tunnels and holes. This problem is compounded by the fact that an underestimate of the fracture zones would also generate an underestimate of the influx of water into the ONKALO.

7 Size of repository – future enlargement

The IMGS Group is concerned by the inclusion in the report Posiva WR 2003-28 of section 4.5 entitled 'Characterization for extension of the repository' which states that the repository design should include the possibility of being used for the disposal of fuel from the possible new nuclear power plants. The Group understood that the present design of the repository is based on the disposal of the fuel from the currently operating power plant units and one new unit, "all with 60 years operational time except the Fortum units with 50 years operational time". The design capacity of the proposed repository is compatible with this. As a lower limit of –600m has been placed on the repository depth (determined by salinity, stress state and major fracture zone (R 21)) any attempt to increase the capacity of the repository would involve either a Multi-story design within the present repository volume and/or the extension of the repository volume laterally into essentially unknown terrain.

The Group feels that this would represent a major modification to the original plans and that this should involve a clear strategy choice. If a decision is made to extend the capacity of the proposed repository an appropriate independent study should be undertaken to achieve this. The Group notes that in many places in the report (Posiva WR 2003-28) the strategy seemed self evident and is concerned with the fact that expansion of the target area seemed to be a recurring theme. The Group also notes that the old structural model is used in this (and other recent) reports.

Similarly, in report Posiva 2003-03 it is stated that …"Additional surface-based boreholes and other types of surface-based investigations will also be needed in order to characterize additional potential repository volumes located outside the area of ONKALO. Such plans are to be reported in the 2003 update of Posiva's RDD programme."

It is clear that plans are in place to extend the repository volume either vertically (multi-tiered) or horizontally. However, when the Group asked about considering the possibility of using other parts of the Olkiluoto peninsula as alternatives to the site selected for the repository, and questioned why there had not been a more thorough investigation of the peninsula, it was told that for various reasons (land ownership, plans for another power plant, the existence of a nature reserve, etc.), the area selected was the only possibility. There seems to be a lack of consistency here which needs clarification.

The IMGS Group consider that the repository limits and capacity should be defined now. Any proposed extension should be subjected to a rigorous investigation and not be achieved by *ad hoc* extensions in the future. Concern was expressed that if conditions are altered too much by any extension, that the capacity of the repository could be overridden with excess heat and the buffer damaged.

The repository location is close to given (Posiva 2003-03). If the repository is extended beyond these limits, the Group's comments, which are made with this particular volume of repository in mind, may no longer be valid.

8 Summary and conclusions

During its two internal meetings in 2003 the IMGS group have been discussing on the problems and the concern related to the Posiva's reports handling with he investigations (partly) completed and the construction procedures going on (already initiated) at the Olkiluoto ONKALO (repository) site. As reported on the previous pages of this report there exists several points we found to be of great importance in the nearest future. The IMGS group members welcome open discussions and "transparent" working reports, e.g. on the following actual and important topics;

- Time table (incl. distribution of reports and time gap allowing a good review before next step in the construction of the repository/ ONKALO).
- Posiva should develop a basic data accessibility plan in consultation with STUK in order to enable external review.
- Assessment of the quality of the original data used in modelling procedures.
- Simplification of models.
- Alternative models.
- Alternative location of the underground galleries.
- Change in strategy (enlargement of the repository at a late stage).

References for the 2003 IMGS Report

Posiva Reports

- Posiva 1999-03. Site scale groundwater flow at Olkiluoto. (Lofman, J.)
- Posiva 2000-07. Site scale groundwater flow at Olkiluoto – Complimentary simulations. (Lofman, J.) Rock strength and deformation dependence on schistosity – Simulation of rock with PFC3D. (Toivo Wanne)
- Posiva 2002-07. Establishing baseline conditions and monitoring during construction of the Olkiluoto URCF access ramp. (Miller, B., Arthur;J., Bruno, J., Hooker, P., Richardson, P., Robinson, C., Arcos, D., West, J.)
- Posiva 2003-02. Baseline conditions at Olkiluoto.
- Posiva 2003-03. ONKAO Underground Characterization and Research Programme (UCRP).
- Posiva 2003-04. Thermal Analysis of Spent Nuclear Fuel repository. (Ikonen, K.)
- Posiva 2003-05. Programme of monitoring at Olkiluoto during construction and operation of the ONKALO.
- Posiva 2003-06. Assessment of Disturbances Caused by Construction and Operation of ONKALO. (Vieno, T., Lehikoinen, J., Lofman, J., Nordman, H. & Meszaros, F.).

Posiva Working Reports

- Posiva Working Report PATU-98-12. 1998. Bedrock models of Kivetty, Olkiluoto Romuvaara sites. – Revisions of the structural models during 1997. (Saksa, P., Ahokas, H., Nummela, J. & Lindh, J.). In Finnish.
- Posiva WR 2001-32. Bedrock model of Olkiluoto, version 2002/1. (Vaittinen et al.) In Finnish.
- Posiva 2002-05 Rock strength and deformation dependence on schistosity – Simulation of rock with PFC3D (Toivo Wanne)
- Posiva WR 2002-36. Host rock classification, Phase 1: The factors that determine the location and layout of a repository – a review. (McEwan, T.)
- Posiva WR 2002-46. Complimentary modelling of the structures west of the proposed repository location – bedrock model v. 2001/2. (Saksa, P., Vaittinen, T & Nummela, J.) In Finnish
- Posiva WR 2003-04. Host rock classification – phase 2: Influence of host rock properties. (Hagros, A., Aikas, K., McEwan, T. & Anttila, P.)
- Posiva WR 2003-09. Effect of Fracturing on Tunnel Orientation using KBTunnel and 3DEC programmes for the repository of spent nuclear fuel at Olkiluoto. (Rautakorpi, J., Johansson, E., Tinucci, J., Palmen, J., Hella, P., Ahokas, H. & Heikkinen, E.)
- Posiva WR 2003-28. Strategy for Construction and Investigation Planning. (Saksa, P., Anttila, P., Reikkola, R. & Hautojarvi, A.)
- Posiva WR 2003-43. Bedrock model of Olkiluoto, version 2003/1. (Vaittinen et al.)
- Posiva WR 2003-46. Controlling of Groundwater inflow into ONKALO and the deep repository. (Riekkola, R., Sievanen, U. & Vieno, T.)
- Posiva 2003-51 Controlling of disturbances due to Groundwater inflow into ONKALO and the deep Repository at Olkiluoto – Summary report.
- Posiva WR 2003-58. Evaluation of Access Routes to the ONKALO Underground Rock ONKALO Underground Rock Caracterisation Facility. (Antti Ikonen, Paula Keto, Timo Saanio, Pauli Saksa, Timo Vieno).

Others

- Report YJT-94-11. Fracture zone analysis of borehole data in three crystalline rock sites in Finland – the principal component analysis approach. Nuclear Waste Commission of Finnish Power Companies (YJT). Helsinki 1994. Korkealaakso, J., Vaittinen, T., Pitkänen, P. and Front, K.
- IMGS 2002 Report. The geological and structural characterization of the Olkiluoto site in a critical perspective. STUK-YTO-TR 196. Radiation and Nuclear Safety Authority (STUK), Helsinki 2003. Cosgrove, J. W., Jokinen, J., Siivola, J. & Tiren, S.
- STUK 2001, Guide YVL 8.5
- STUK 2002, Guide YVL 8.4.