SITE SPECIFIC INFORMATION IN SITE SELECTION

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Abstract

The programme for the siting of a deep repository for final disposal of spent nuclear fuel was started already in 1983 and is carried out today by Posiva Oy which continues the work started by Teollisuuden Voima Oy (TVO). The programme aims at site selection by the end of the year 2000. The programme has progressed in successive interim stages with defined goals. After an early phase for site identification, five sites were selected in 1987 for preliminary site characterisation. Three of these were selected and judged to be best suited for the more detailed characterisation in 1992. An additional new site was included into the programme based on a separate feasibility study in the beginning of 1997.

Since the year 1983 several safety assessments together with technical plans of the facility have been completed. When approaching the site selection the needs for more detailed consideration of the site specific properties in the safety assessment have been increased. The Finnish regulator STUK has published a proposal for general safety requirements for the final disposal of spent nuclear fuel in Finland. This set of requirements has been projected to be used in conjunction of the decision making by the end 2000.

Based on the site evaluation all sites can provide a stable environment and there is evidence that the requirements for the longevity of the canister can be fulfilled at each site. In this manner the four candidate sites do not differ too much from each other. The main difference between the sites is in the salinity of the deep groundwater. The significance of differences in the salinity for the long-term safety cannot be defined yet. The differences may contribute to the discussion of the longevity of the bentonite buffer and also to the modelling of the groundwater flow and transport. The use of the geosphere as a transport barrier is basically culminated on the questions about sparse but fast flow routes and "how bad channeling can be". To answer these questions based on site specific information and evaluate the uncertainty is an important part of the discussion in the integrated work between site characterisation and safety assessment.

1 Introduction

The stepwise approach for site selection in Finland was included in the Council of State's Decision in Principle on the nuclear waste management in 1983. Based on this decision the site should be selected by the end of 2000 based on the systematic programme of identification, characterisation and evaluation. As the first step of this programme the bedrock of the whole country was evaluated during the years 1983-1985 to be able to locate potential candidate sites for the site characterisation in practice. Based on this work and the assessment of other factors, the second step of the programme, preliminary site characterisation was commissioned at five potential sites in 1987. This work was concluded at the end of 1992 in accordance with the overall programme. Since 1993 more detailed characterisation has been in progress on three sites, and a new additional site was included in the programme in the beginning of 1997.

At the three earlier sites, namely Kivetty in Äänekoski, Olkiluoto in Eurajoki and Romuvaara in Kuhmo, several deep boreholes have been drilled and comprehensive surface investigations already carried out since 1987. Therefore, very little additional information can no longer be achieved by surface based investigations at these sites. The fourth site, Hästholmen in Loviisa, is currently a target for an intensive investigation aiming at the evaluation of the site in parallel with the three other sites.

Which of the candidate sites will be selected for the final disposal is, of course, a sum of many factors. When deciding upon the site the following conditions have to be fulfilled

- the safety authority has to give the preliminary statement on the safety
- the local community has to accept the proposed project
- the Council of State has to approve the project and the Parliament has to ratify the decision

Before any nuclear facilities can be built in Finland the Council of State's Decision in Principle, based on the Nuclear Energy Act, is needed as the first step for implementation. This decision can be regarded as "a general permission" in the licensing process. At the later stages, the applications for construction license and the operation license are the following steps with their own processes.

The process for this decision making will be initiated by Posiva when submitting an application for this decision to the Government. Before the Government can make the decision it has to ask the approval of the communities which host the potential site candidates for the facility. The communities can exercise their right of veto on this matter in case they do not accept the facility. Before its own decision the Government has to also ask the Radiation and Nuclear Safety Authority (STUK) for the preliminary statement on the safety. When considering the decision the Government has to keep in mind the overall good of the society comprising the need for the facility, the suitability of the site and the environmental impacts assessed. In case the Government's decision is positive for final disposal the decision has to be subjected for the approval of the Parliament.

This paper discusses the role of site specific information in the process of site selection. The site selection is, as presented above, a decision process involving also a dimension for political decision making. In this paper, however, the viewpoint is kept in the geoscientific information and in the evaluation of geosphere in the course of the site selection research programme.

2 Important Questions

The framework for the discussion in this paper has been sought by reiterating the following key questions for the site selection for final disposal, and these are

- what is the role of the geological barrier ?
- what are we looking for from a suitable geological environment ?
- how good a geological barrier is needed ?

When dealing with these questions the experience and information from the site selection research programme implemented in Finland is kept in mind. However, the questions above are not unique to the Finnish programme only but also discussed during the past years at the international arenas.

The purpose of the final disposal at the great depth in a geological formation is to remove the spent fuel from man's environment and place it out of reach of major disruptive processes. The geological formation is expected to provide an environment where the rates of natural processes affecting the canisters and spent fuel are slow and a thick layer of crystalline bedrock should as well provide an adequate shielding against a release of radioactive material from the waste itself.

The final disposal, however, is not based on the properties of the geological formation alone but consists of the multibarrier system planned for final disposal to isolate the waste from man's environment. The multibarrier system discussed in this paper comprises the fuel itself, the engineered barriers, that is copper canister and bentonite buffer, and crystalline bedrock as the natural barrier. The primary function of the bedrock is to provide stable mechanical and chemical conditions over the long periods of time so that the long-term performance of the engineered barriers is not jeopardised.

The main reason on the relative importance of the engineered barriers is that normally in the nuclear technology the safety can be based on the systems built from materials fully characterised and investigated, and if not so, the behaviour of which can be monitored to maintain the safe operation. At the great depth of the crystalline bedrock practically no technical improvements can be made regarding the long-term gross properties of the bedrock, and the basic question is how well it is possible to characterise the properties of the bedrock to be used in the preliminary repository design and in the site specific safety assessment. Due to the known heterogeneous nature of the geological environment and uncertainties associated the main emphasis for the safety assessments has

been to develop reliance on the understanding of behaviour of the engineered barriers and the various processes in the near-field of the repository.

The contribution of the geological barrier of the deep repository to the safety is thus the physical protection of the disposal system as a whole. If something should happen the geological barrier should be able to restrict the possible radionuclide releases from the repository and through sorption and matrix diffusion be able to retard and retent the radionuclides escaped from the repository into the crystalline rock so that they do not form a risk in man's environment.

Finally, many safety cases have shown that the safety-related requirements are probably met by most sites identified and characterised in the crystalline basement areas (SKB-91, TVO-92, Kristallin-I, AECL, SKI-94, TILA-96) as candidate sites for a deep repository. This raises the question how good a geological barrier shall be as a whole. The waste will finally be placed in such bedrock volumes, characterised in great detail at depth, which most likely are able to provide an effective isolation, and bedrock sections which are regarded less promising are rejected from the repository volume.

In the following chapter it is described how the site information has evolved in the Finnish programme and how it has been used in the site evaluation so far.

3 Evolving Site Information

3.1 Identification of Potential Candidate Sites

The first step of the site selection research in Finland was to identify potential investigation sites to be able to select several sites for practical field investigations. In thinking the properties of a possible area for siting the following principles were applied (TVO 1992)

- a predictable environment was needed, preferably in all scales. This meant that homogeneity was preferred in rock types and more homogenous areas were judged to be more amenable to investigation

- low regional and local hydraulic gradients and low hydraulic conductivity of the bedrock were properties desired to ensure low groundwater flow rates and to provide longest possible transport times

- it was evident that the repository should be located away from potential tectonic zones and potential fast geosphere pathways

- the site to be selected should represent geological environment that has evolved only slowly and is currently relatively stable

- in order to minimise the possibility for inadvertent human intrusion the site should consist of common rock types, abundantly available

The geological starting point for the localisation of site candidates was to define " bedrock blocks" delineated by large fault zones interpreted from various sources of geological and geophysical information. The block areas were large, typically more than 100 km^2. Inside these block areas smaller blocks were analysed being simultaneously elevated areas representing groundwater recharge areas thus having as long as possible flow routes.

It was evident that at this stage the site information from a greater depth was incomplete and was based mainly on the interpretation of various existing geological, hydrogeological, geochemical and geophysical materials. During the course of the work, applying the principles mentioned above, it was obvious that the potential areas identified as an outcome of the studies became rather similar in their properties. This has to be kept in mind when discussing possibilities for later comparisons.

3.2 Preliminary Site Characterisation

Five areas were selected for the preliminary site characterisation in early 1987 (TVO 1992). These areas were selected from a great number of potential candidates. The sites represented different geological main units of the Finnish Precambrian bedrock in various parts of the country.

When considering the sites for selection the question of acceptance of the local communities was taken into consideration by having discussions with communities which had a candidate site within its territory. The purpose of these discussions was to identify the communities willing to cooperate at this stage and ensure that the communities allow the start of field investigations for preliminary characterisation. In judging the potential sites also possibilities for practical site exploration were considered.

In the course of the planning the programme for preliminary characterisation for the years 1987-1992 attention was drawn to following

- investigate the structure of the local bedrock to define the possibility for physical isolation of the engineered barrier system of the deep repository in the suitable bedrock volumes
- investigate the properties of the site to be able to model the potential groundwater fluxes through the repository and evaluate their significance
- investigate the groundwater chemistry to evaluate the impacts on the engineered barrier system
- study into long-term stability of tectonics, hydrogeochemistry and hydrogeology
- study into constructional and operational feasibility for the assumed amount of the waste

Based on the investigations at the sites it was possible to evaluate the gross properties of the bedrock. The geological features, geochemical conditions and hydraulical proper-

ties were good regarding the final disposal. The analysis exposed that each site candidate in principle could host a repository and no adverse properties existed. In the modelling of the bedrock structure some of the candidate sites were judged more complex than others (TVO 1992). The degree of certainty in interpreting results and inferring meaningful information from these for developing structural models was one of the important factors when judging the success for further site characterisation. The expectations to be successful in the further investigation was the reason for excluding two of the sites from the programme.

In the analysis of the groundwater flow a large contrast in flow distribution between averagely fractured rock volumes and fractured zones was assessed. The mean flow rates in the intact, averagely fractured, bedrock were estimated to be very low. The problem of faster pathways, however, was noted and in the safety assessment TVO-92 (Vieno et al. 1992) they provided a potential by-pass of the geological barrier as a conservative way to assess the safety of the deep repository. It was evident that the detection and analysis of fast pathways should become a significant part for the further site characterisation. The question "how bad can channeling be" was raised.

3.3 Detailed Site Characterisation

The current stage started in 1993 and aims at site selection in the year 2000. This eight year period has been divided into two stages for the years 1993-1996 and 1997-2000.

The work during the years 1993-1996 was divided into three sub-programs: 1) the baseline investigations describing the present conditions in the bedrock, 2) the additional characterisation for the acquisition of complementary data, and 3) the investigations for testing the earlier results and hypotheses to build confidence in existing understanding (Posiva 1996).

The baseline investigations have characterised the groundwater chemistry and its variations at the sites, as well as, summarised hydrological observations of Kivetty, Olkiluoto and Romuvaara. Saline groundwaters were found at Olkiluoto and results indicate that the salinity increases towards the depth. The state of the rock stress measured in deep boreholes correlates rather well with the general knowledge of rock stress in Finnish bedrock. Based on the interpretation of additional characterisation work carried out some complementary structural features were added, and some changes in earlier features were made to the bedrock models. The developments in the models did not, however, impede locating the vault at the desired depth in the bedrock.

The TILA-96 report (Vieno et al. 1996), a continuation and update of the TVO-92 safety analysis, confirmed that the planned system for spent fuel disposal fulfils the proposed safety criteria. Provided that no major disruptive event hits the repository, initially intact copper canisters preserve their integrity for millions of years and no significant amount of radioactive substances will ever escape from the repository. Impacts of potential canister failures have been analysed employing conservative assumptions, models and data. In the case of single canister failures, the results show that the margin to the proposed regulatory criteria is more than three orders of magnitude in the dose rate and more than four orders of magnitude in the release rates into the biosphere. Even

in the extreme cases, where all 1500 canisters are assumed to be initially defective or to "disappear" simultaneously at 10 000 years in the "worst possible location" in the repository, all the proposed safety criteria would be passed. When realistic modelling and data are used in the consequence analyses, the results show negligible releases and doses.

The TILA-96 report suggested for the further site characterisation and evaluation of the candidate sites that emphasis should be on three topics: I Evaluation of the geological structure and fracturing of the bedrock, II Identifying of bedrock volumes, where the repository could be constructed, and their assessment from the construction point of view, III Assessment of geochemical conditions (the role of brackish and sulphate-rich, saline, and very saline groundwaters).

In the present work which comprises also Hästholmen in Loviisa as a candidate site these questions have been introduced into two main areas, on the one hand there is the need to study the uncertainties related to geometry of fracture zones and fracture network of the site to be able to locate the potentially advantageous volumes for repository lay-out, and on the other hand improve the consistency between hydrogeology and hydrogeochemistry to understand the processes affecting the assumed stability of site candidates. This is needed because

- each site candidate has complex groundwater flow and solute transport paths
- has potential to fast pathways
- redox buffering capacity is difficult to demonstrate by direct investigations

The information from deep drillings and updating of the conceptual bedrock models enhanced the idea of the complexity of the geological barrier due to the heterogeneity. This leads to the fact that hydrogeological modelling will be associated with considerable amount of uncertainty and the transport in the geosphere will be dominated by properties of preferential flow paths such as WL/q ratio of each transport path. The question is how much site specific information can be produced to specify this parameter.

In the current work more emphasis has been put on hydrogeochemistry. The improved sampling techniques and increased number of samples have produced information on the existing chemical conditions at the sites. Overall, the sites seem to be in a postglacial quasi-static state containing "old" groundwaters, both fresh and saline, with efficient redox buffers. Hydrogeochemical modelling seems to be in accordance with structural geological information and hydrogeological interpretations. The work, however, is still underway. Paleohydrogeochemical techniques may provide some bounds for the estimation of future conditions to be used in the safety assessment.

The safety assessment work, aiming at TILA-99 report, has been integrated into the site characterisation together with some parts of the engineering aspects to enable a meaningful site evaluation.

4 Towards Decisions

4.1 Preliminary Safety Requirements

Finnish Centre for Radiation and Nuclear Safety (STUK) has prepared a proposal for general regulations concerning the disposal of spent nuclear fuel (STUK 1997). The proposal has been targeted to give support to the Council of State's Decision in Principle and site selection. After the period for commenting and preparation the general regulations are submitted to the Council of State for the approval.

Considering the siting of the deep repository the proposal contains among others following requirements:

- The geological characteristics of the disposal site shall, as a whole, be favourable for the containment for the nuclear waste to be disposed of. Areas having features that are substantially adverse to safety, shall be avoided in the selection of the disposal site.

- At the planned disposal depth, blocks of bedrock with suitable size and intactness shall exist for the construction of the repository. For the planning of the repository and to acquire data needed for the safety analysis, the host rock shall be adequately characterised by means of investigations performed at the planned disposal depth.

- The models and data introduced in a safety analysis shall be based on the best available experimental data and expert judgement. The models and data shall be selected on the basis of conditions that may exist at the disposal site in each time period considered in the analysis and they shall be adequately site specific and mutually consistent, taking account of the available investigation methods. The safety analysis shall, with good confidence, aim at overestimating the radiation impact likely to occur. The significance of uncertainties involved with safety analysis shall be estimated.

These requirements mean that the site selection can be based on the surface based investigations which are allowed to contain uncertainties. No extraordinary characteristics are required from a site to ensure the long-term safety of a deep repository for spent fuel.

4.2 Site Specific Information and Safety Assessment

Referring to the above mentioned requirements it is obvious that one important task for the upcoming safety assessment TILA-99 is to analyse the conditions necessary for safe disposal of each site. After this sites can be treated as candidates for further selection. In case the assessment would show signs of unacceptable conditions at a site, this site should be rejected from the selection process.

The requirements call for site specific information to be used in the models and calculations, however, on the other hand the safety analysis should be simultaneously conser-

vative and aim at overestimating the possible impacts. This means that the direct comparison of the sites, using the results of safety analysis as such would not be very meaningful.

How good a geological barrier shall be, and what would make another site more advantageous than another? It is obvious that in the normal evolution scenario of the safety assessment the geological barrier at all sites can provide the basic demand of physical isolation from man's environment. The preliminary results of TILA-99 seem to support the earlier conclusions of TILA-96 (Vira et al. 1998) The most important characteristics of a suitable site are related to groundwater chemistry providing stable conditions for copper, and an environment for slow dissolution and low solubility of radionuclides. The other good properties of a site are if the probability for fast flowing features is low and the mineralogy of the bedrock is such that it can retent potential radioactive solutes in the groundwater. The technical concept, however, can be adapted to the geological conditions at depth so that it is possible to avoid, at least to a certain extent, fast flowing features.

The geological barrier is mostly needed if something unexpected would occur and weaken the good properties of the technical barriers. The question if some of the candidate sites would be more vulnerable for disruptive events in the future in the conditions of Finland causing major changes in the presently stable environment is not possible to predict quantitatively. In a case where a copper canister or several canisters would loose their integrity is decisive if this should happen next to a fast flowing feature. Based on the investigation methodology today it is not possible to say whether this would be more likely at some of the sites.

The most apparent difference between the candidate sites is that Olkiluoto and Hästholmen are presently located at the coast of the Baltic Sea, whereas Kivetty and Romuvaara are inland sites lying about 200 meters above the sea level. At the depth of 500 meters and downwards, groundwater is brackish or saline at Olkiluoto and Hästholmen, whereas it is fresh in Kivetty and Romuvaara. Salinity of the groundwater seems to affect to some degree negatively the near-field properties and retardation but on the other hand, salinity has been regarded often as a sign of very low or stagnant flow conditions and prevent humans of drinking such a water.

5 Summary

Site selection research has been a long process in Finland during which the site information has evolved gradually. During the process this information has been evaluated also by the means of safety analysis, starting from studying the feasibility of the final disposal based on generic information and ending up using the site specific properties aiming at assessing the bedrock volumes suitable for repository purposes.

The process has shown that the differences in the main properties of the bedrock in the different parts of Finland are rather small and similar suitable bedrock volumes can be identified at many sites. The citizens in the communities, as well as, the other decision

makers have their primary interest, however, in the safety of the final disposal and it is understandable that the idea of the "best possible site" is supported.Therefore the importance of small differences in site information have to be studied, evaluated and explained in the process.

The main role of the geological barrier is to provide an effective isolation of the waste, and we are looking forward mostly to mechanical and geochemical stability into the future from the geological environment at the site to be selected. Is any of the present sites more or less favourable than others comes down to a question of uncertainty. How well are we able to find and assess properties of suitable bedrock volumes at a particular site is one of the important questions ?

6 References

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