DISCUSSION

Peter Baumgartner, AECL

Could you discuss your stability criteria for the rock mass, in terms of both the short-term and the long-term implications of that stability? What criteria did you use in the design in terms of the mechanical stability of the rock, was it short-term criteria, or a long-term criteria, and what definitions did you use?

Keiji Hara, PNC

The study information is that factors such as the long-term mechanical behaviour of the rock, are much less important than stability of the engineered barrier systems. The rock deformation is not a major issue, whether or not the formation is hot.

2.2 DESIGN PRINCIPLE OF TVO'S FINAL REPOSITORY AND PRELIMINARY ADAPTATION TO SITE SPECIFIC CONDITIONS

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ABSTRACT

Teollisuuden Voima Oy (TVO) is responsible for the management of spent fuel produced by the Olkiluoto power plant. TVO's current programme of spent fuel management is based on the guidelines and time schedule set by the Finnish Goverment. TVO has studied a final disposal concept in which the spent fuel bundles are encapsulated in copper canisters and emplaced in Finnish bedrock. According to the plan the final repository for spent fuel will be in operation by 2020. TVO's updated technical plans for the disposal of spent fuel together with a performance analysis (TVO-92) were submitted to the authorities in 1992. The paper describes the design principle of TVO's final repository and preliminary adaptation of the repository to site specific conditions.

1. INTRODUCTION

The waste producer is responsible for the safe management of radioactive wastes in Finland. TVO, which operates two BWRs (2 x 710 MW(e)), is making preparations for the final disposal of the spent fuel in Finnish crystalline bedrock. TVO's current programme of spent fuel management is based on the guidelines and time schedule set by the Finnish Government. Accordingly, TVO is preparing to have a final repository for spent fuel operating by 2020. Until then, spent fuel will be stored at the reactors and at the interim storage facility operating at the power plant site since 1987.

In accordance with the Government guidelines, TVO is running site investigation programme. Since 1987 five sites (Fig. 1) have been the subject of studies to examine their suitability for hosting a repository. The results from these studies were available by the end of 1992 (Teollisuuden Voima Oy 1992a), when three sites were selected for further characterization. The final selection of the host site will take place in 2000, allowing the start of construction of the repository in the 2010s.

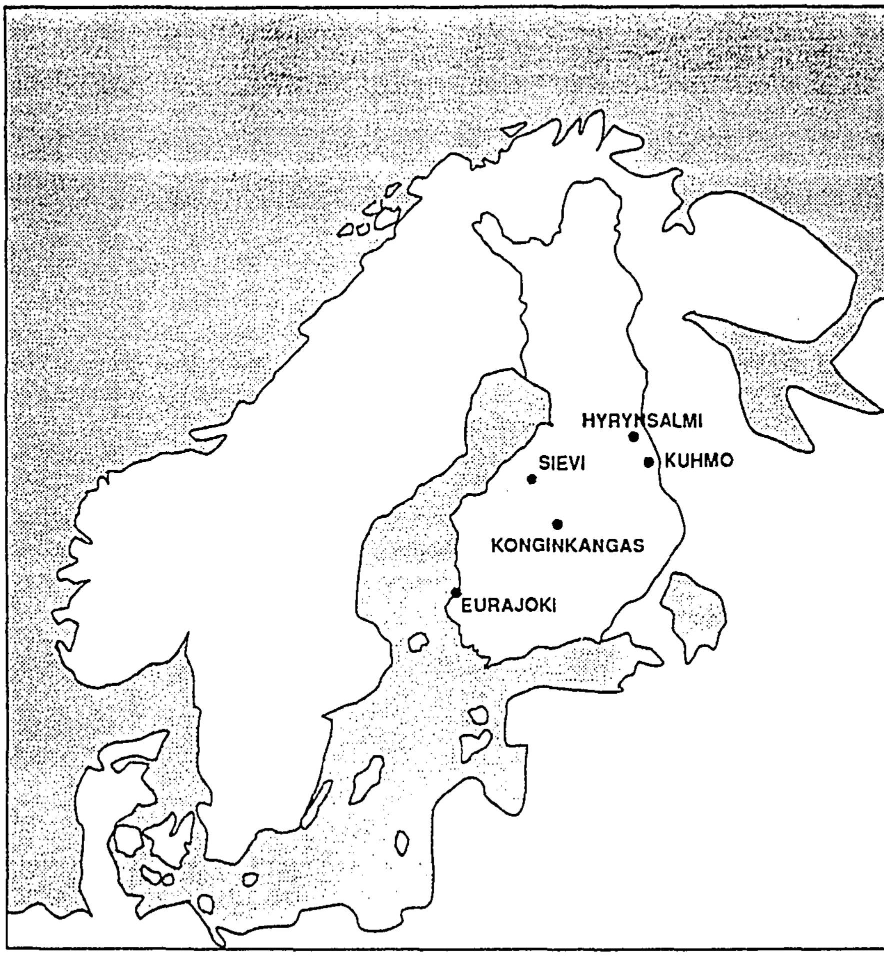

Figure 1. The sites of preliminary investigations for the final disposal of spent nuclear fuel in Finland.

Parallel to the site investigation programme, an R & D programme has been run with the aim of developing the technology for encapsulation and disposal and extending the database and modelling capabilities needed in performance assessment of the chosen technical concept. Updated technical plans together with the performance analysis of spent fuel disposal (TVO-92) (Vieno et al 1992) were submitted to the authorities by the end of 1992 (Teollisuuden Voima Oy 1992b).

This paper will describe the updated technical plans for TVO's spent fuel disposal, which also form a basis for TVO-92. The spent fuel is encapsulated by a cold process technique (Mayer et al 1989) in advanced cold process (ACP) canisters (Raiko et al 1992). The repository design (Salo et al 1990) was completed in 1989.

In TVO's disposal plan the total spent fuel amount is estimated to be 1840 tU, corresponding to approximately 1200 ACP canisters. The manufacture of 1200 final disposal canisters would require around 8000 t of copper and 5000 t steel.

2. REPOSITORY CONCEPT

The report on the preliminary repository design (Salo et al 1990) includes a description of the repository facilities, structures and necessary systems. The design capacity of 1200 canisters can be expanded if needed later on.

The repository layout consists of a system of a central tunnel and parallel disposal tunnels (Fig. 2). The central tunnel makes a loop around the repository area. The minimum total area of the repository comprises about 250 m x 860 m. Three closely situated vertical shafts lead from the surface to the repository: a canister transfer shaft, a personnel shaft and a work shaft.

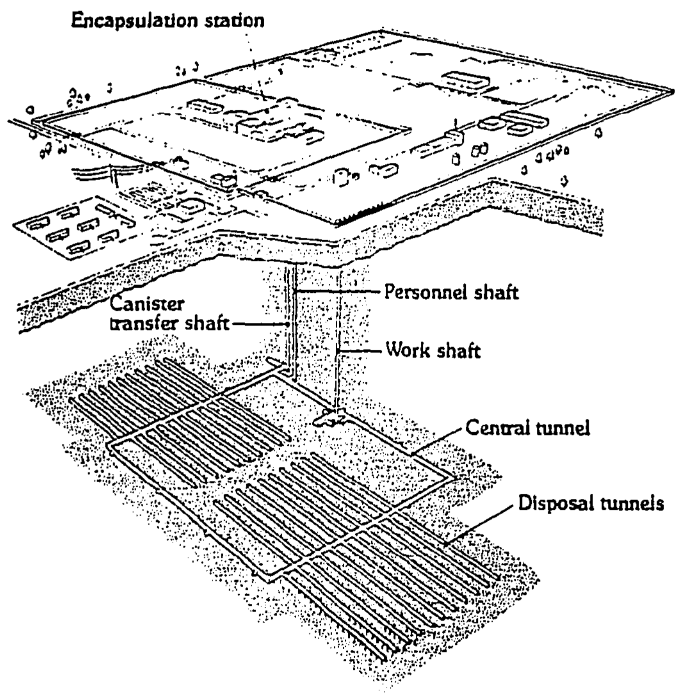

Figure 2. The planned final disposal facility for TVO's spent fuel

The total excavation volume is about 240 000 m^3, of which the shafts account for 32 000 m^3 and the disposal tunnels about 136 000 m^3. The rest of the volume is taken up by the central tunnel and auxiliary space. The repository, including deposition holes for canisters, will be totally excavated and constructed before the start of the operation.

The ACP canisters will be emplaced in vertical holes in the floors of the horizontal disposal tunnels (Fig. 3). In the deposition holes the canisters will be surrounded by bentonite clay forming a buffer of very low hydraulic conductivity between the canister and the rock. Each disposal tunnel will be backfilled with a mixture of sand and bentonite immediately after the emplacement of canisters in all the holes of the tunnel has been completed.

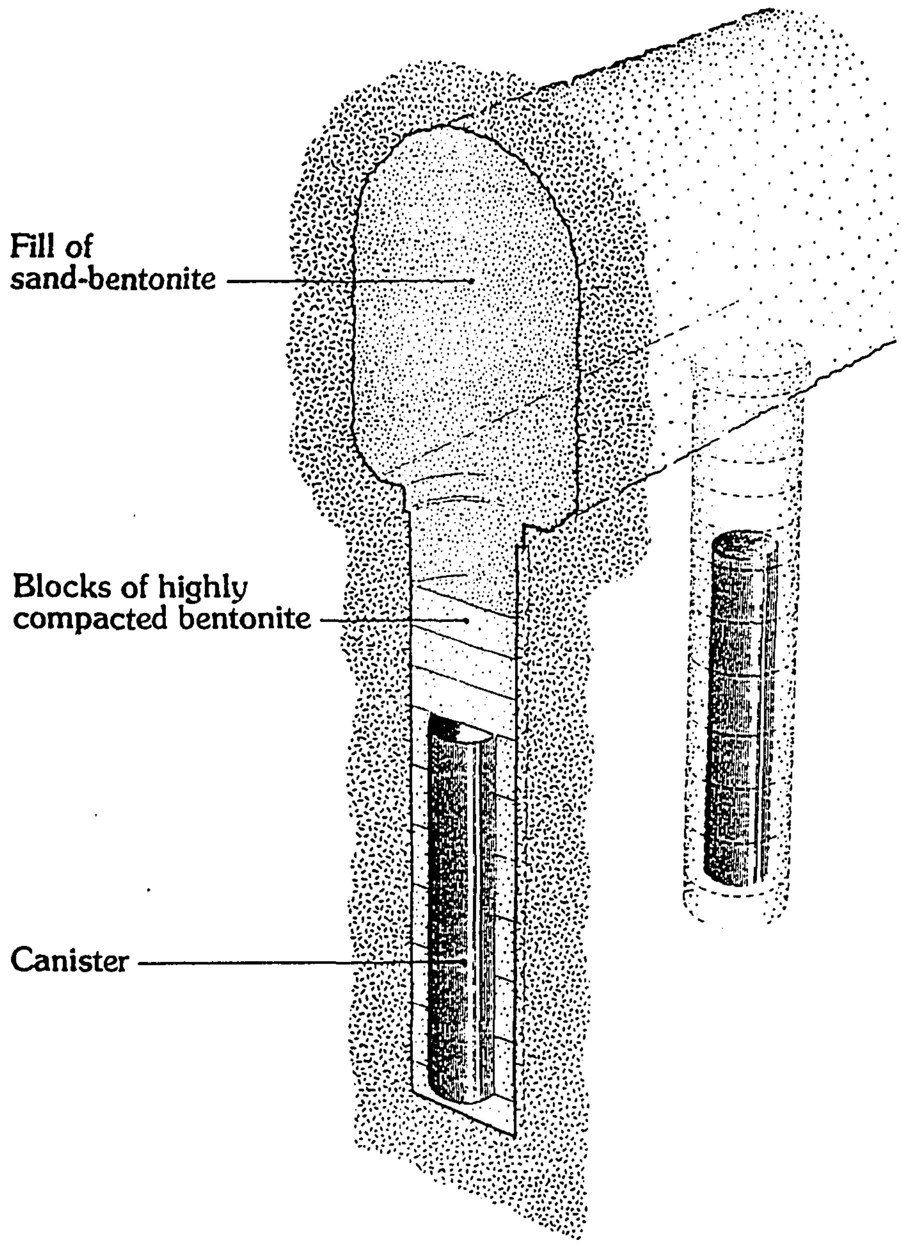

Figure 3. ACP-canister in deposition tunnel

When the encapsulation station is decommissioned all the contaminated systems and structures will be removed and disposed of in the repository too. Finally, the central tunnel and the shafts will be sealed with a mixture of sand and bentonite.

An alternative repository layout (Salo et al 1990) was also designed. In this alternative the work shaft is set apart from the other shafts (Fig. 4). Different layout alternatives guarantee flexibility when optimizing site specific layouts in relation to local bedrock conditions. The distance between canister deposition holes, the length of a disposal tunnel and the shaft positions can be adjusted according to local needs.

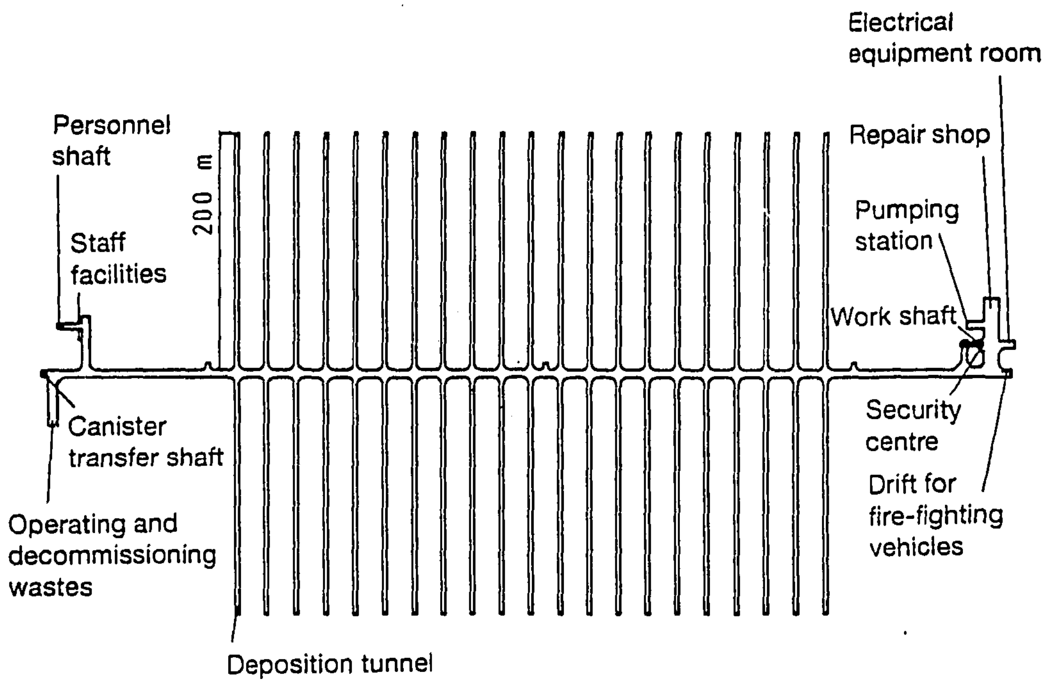

Figure 4. Alternative layout for the final repository.

3. SITE SELECTION

According to the decision in principle of the Council of State. TVO must indicate a location during the year 2000 where the final repository for spent fuel can be constructed. Preliminary screening to identify a number of areas suitable for preliminary investigations was started in 1983. A total of 102 potential sites were named, of which five were finally selected in 1987 for preliminary site investigations (Teollisuuden Voima Oy 1992a). These five potential sites were situated in the municipalities of Eurajoki, Hyrynsalmi, Äänekoski (Konginkangas before the fusion of the two municipalities in 1993), Kuhmo and Sievi. The areas are situated in different parts of Finland, see Fig. 1, and they represent the main formations of the Finnish bedrock.

The field investigations comprised airborne and ground geophysical surveys, geological mapping and sampling, deep and shallow core drilling, geophysical and hydrological borehole measurements and groundwater sampling. The deepest boreholes drilled at each area were about 1000 m long.

The hydraulic conditions in the areas are rather similar. The measured values of hydraulic conductivity in rock matrix are in most cases smaller than 10^{-9} m/s. Conceptual 3-dimensional bedrock models were interpreted for each area, and they contain typically 20 - 30 fracture zones.

As the final stage, based on the conceptual geometrical models, groundwater flow analyses were performed for each of the five sites. The hydraulic head distribution and flow rate were solved by the model calculations based on the porous continuum approach both in the rock matrix and in the fracture zones. Flow rate varies in the rock matrix typically between 0.01 and 0.1 l/m^2a.

The measured Eh-values of the groundwater indicate reducing conditions. Sulphide content is typically small. Saline waters were sampled at two areas, Eurajoki and Sievi.

4. ADAPTATION AND CONSTRUCTION OF THE FINAL DISPOSAL PLANT

From 1990 to 1992, TVO studied whether the soil and rock conditions at the five sites were suitable for the location and construction of the final disposal plant. At the same time, the feasibility of building the repository in the bedrock of the investigation site was examined. The studies showed that the local soil and rock conditions permit the construction of the final disposal plant at any of the investigation sites. In addition, the deposition tunnels and holes, including any extensions, can be incorporated in the blocks defined by the crush zones in various ways.

Beside the preliminary location studies, the differences in the construction of the final disposal plant at the different sites were compared. The comparative analysis of the feasibility of the construction of the final disposal plant for TVO's spent fuel (Riekkola et al. 1992a) examined the road connections, municipal engineering services and availability of labour. Also, the effect of the type of soil and bedrock involved, groundwater characteristics and local climate on the feasibility of construction was investigated. This area-specific comparison revealed no significant differences between the various sites with regard to constructing the facility. In terms of costs, Olkiluoto and Kivetty were about FIM 10 to 50 million less expensive than the other sites.

One of the basic aims of the preliminary location studies (Riekkola et al. 1992b-f) was to compare the effect of the various location criteria on the layout and tunnel length of the repository. This was done to formulate an idea of how the various factors affect the technical feasibility of the final repository. At the same time, the studies carried out provided a basis for layout optimization and future site investigations. However, the adaptation of the repository to the selected bedrock will be based on a comprehensive analysis aiming at the best possible system in terms of long-term safety, with due regard to the feasibility of construction and other engineering considerations.

The factors considered were the location and properties of crush zones, groundwater flow in the investigation site, bedrock fracturing, stress state, strength characteristics, groundwater chemistry and above-ground conditions in the area of the shafts. Overall, it is not possible to find the best solution with regard to all these factors, and therefore the final outcome will be a compromise between them.

In the course of the location studies, the area in the vicinity of the boreholes was investigated at a depth of 500 m. The properties of the bedrock in this area are known in sufficient detail to permit the comparison of different location criteria.

To take account of the crush zones, three different and progressively more stringent location rules (A, B, C) were developed. These location rules specify the minimum distance of the deposition tunnels and disposal holes from the crush zones classified as significant from the point of view of hydraulic conductivity or structural engineering. The central tunnel linking the deposition tunnels was allowed to intersect all fracture zones.

The deposition tunnel is to be oriented so that the main fracture direction is intersected as perpendicularly as possible. This will keep the number of waterconducting fractures parallel to the tunnels in the rock surrounding the deposition tunnels to a minimum. This tunnel orientation is also favourable from the point of view of excavation because rock boring can then be carried out more easily and the need for reinforcement is probably minimal.

On the other hand, it seems sensible to orientate the tunnels parallel to the maximum horizontal stress of the rock, which improves the rock-mechanical stability of the tunnels.

With regard to groundwater flow , the deposition tunnels and disposal holes should be located in an area where groundwater flows downward or horizontally. Then the flow distances from the facilities to the ground will be longer than if the flow direction is upwards. If the investigation site contains saline groundwater, the facilities should be located in the saline groundwater area because the groundwater flux is there lower and it takes longer to reach the biosphere than in a fresh groundwater zone.

The conditions prevailing on the ground in the area of the shafts affect the structure of the upper end of the shaft and the foundations of the encapsulation plant. With regard to these structures, the best conditions are offered by exposed rock or thin layers of soil on top of the rock.

Draft plans used in the preliminary location studies revealed that when moving from location rule A to rule C, the deposition tunnels were distributed into more rock blocks separated by fracture zones. Variations in the total length of the tunnels were less than 10% in the different layouts. The location rules had little effect on the length of the central tunnel. In the areas covered by the borehole studies at Romuvaara, Kivetty and Olkiluoto, there is slightly more freedom for locating the repository than at the other sites.

For the groundwater computations included in the TVO-92 Safety Analysis, the final repository was assumed to be located in the bedrock at the Veitsivaara investigation site. This made it possible to take into account realistically the actual conceptual 3-dimensional structure of the bedrock complete with crush zones. Veitsivaara was selected to serve as an example because at the time when the groundwater analysis was begun in the spring of

1991, site investigations and their reporting were more advanced at Romuvaara and Veitsivaara than at the other sites. Moreover, Veitsivaara was regarded as a "challenging" site from the point of view of modelling owing to its geometrically complicated crush zone pattern.

At the Veitsivaara investigation site, the area housing the repository borders on structure R1 in the north and structure R21 in the middle, running in the north-south direction (see Fig. 5). In the Veitsivaara repository location study, the final repository has been located at a minimum distance of 100 m from structure R1 and at least 50 m from structure R21.

The repository used in the groundwater computations for the purposes of the TVO-92 Safety Analysis is located at a depth of 500 m in the vicinity of boreholes KR1 and KR2 (see Fig. 1). The western section of the repository is assumed to be excavated in gneiss, the eastern section in granite. The boundary between gneiss and granite runs along the crush zone R11. In this case, the deposition tunnels are allowed to intersect structure R15, which is not significant from the point of view of rock engineering and hydraulic conductivity.

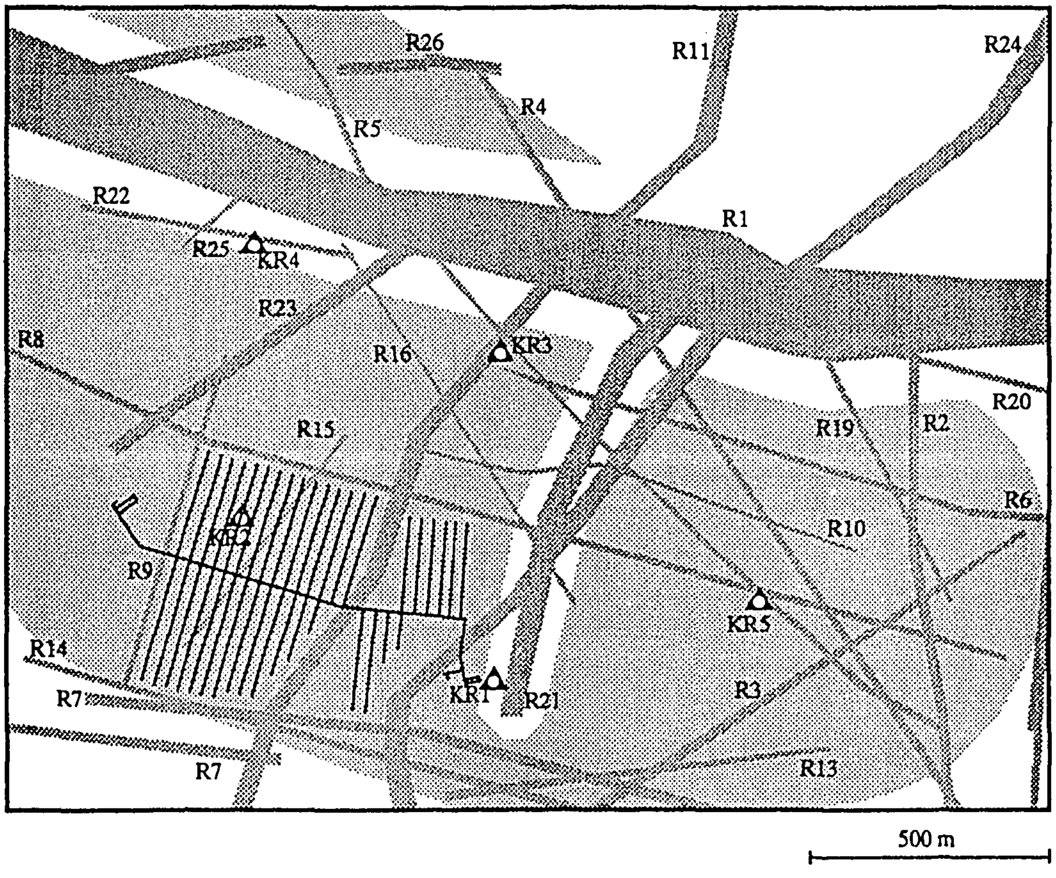

Figure 5. Example showing how the repository can be adjusted to local fracture zones (Veitsivaara).

The basis for this location is based on the alternative layout of the final repository shown in Fig. 4. The personnel access and canister shaft leading to the repository are located on a hill near borehole KR1, where the encapsulation plant can be built. The work shaft will be located on the Veitsivaara hill.

The terrain at the Veitsivaara investigation site slopes from east to west and the corresponding groundwater level induces a local general gradient modified, to some extent, by local details. However, the depth-dependence of the hydraulic conductivity of the rock and crush zones is not necessarily very great so that the crush zones with the highest hydraulic conductivity take heads equivalent to groundwater levels deep into the bedrock regardless of minor local variations. Crush zone R1 with a high hydraulic conductivity takes, in particular, the lowest heads deep under the Veitsivaara rock.

The deposition tunnels are located far from crush zone R1 and on top of it. As a result, there is a downward and westerly pressure head gradient in the area where the repository is to be constructed. However, between the deposition tunnels and crush zone R1 there are several hundreds of metres of rock so that other crush zones (R8, R9 and possibly, to lesser degree, R15) are first located in the flow path of the groundwater from the deposition tunnels and disposal holes.

5. TVO-92 SAFETY ANALYSIS

An updated post-closure safety assessment TVO-92 (Vieno et al. 1992) based on the present encapsulation technique and the results of site studies were submitted to the authorities in December 1992. The assessment consists of two main branches, the first of which corresponds to expected evolution scenarios and the second one to various cases of disruptive events and unexpected evolution. The results of the assessment show that the planned disposal system fulfils the safety requirements and criteria proposed by the Nordic authorities.

In the prevailing conditions of the geosphere, the copper-steel canisters will remain intact for millions of years. The very long-term releases consisting mainly of I-129 and some long-lived actinides and their daughters are insignificant from the point of view of radiological safety.

The stability and low solubility of spent fuel, the buffer and the geosphere restrict efficiently the release of radionuclides even if the canister is initially defective or is broken soon after the sealing of the repository. The analysis also includes the evaluation of consequences of a very unlikely disruptive event, in which a large post-glacial rock shear is assumed to intersect the repository and break a number of canisters. Even if the rock shear occurred already after 1000 years and damaged all the 60 canisters in one deposition tunnel and, in addition, there were oxidising conditions in the geosphere because of the glacial melt water, the resulting dose rate would be smaller than the dose rate caused by the natural background radiation.

In the flow calculations included in the TVO-92 Safety Analysis, the hydraulic conductivity of the crush zones intersecting the repository and of the repository itself was selected very conservatively. This made it possible to consider the importance of any U-tube flow. These selections ensured that the computed flow regimes are more unfavourable than actual flow regimes at any of TVO's five investigation sites. The safety analysis also examines the effect of other types of flow regimes and volumes on the release and migration of radioactive materials.

6. CONCLUSIONS

The results of the studies in the years 1987 - 1992 showed that with respect to important properties of the bedrock all sites provide conditions for safe final disposal. The planned repository can also be located in each area. However, there are less uncertainties in the conceptual bedrock models at the sites at Eurajoki, Kuhmo and Äänekoski and the explorability of these sites is more favourable than that of the two other sites. Hence, Eurajoki, Kuhmo and Äänekoski were selected for detailed site investigations for the years 1993 - 2000.

No extraordinary characteristics are required from a site in crystalline bedrock to warrant the long-term safety of a deep repository for spent nuclear fuel. The main functions of the geosphere in the disposal system are to protect the waste from human and other external actions and to provide stable mechanical and chemical conditions for the repository.

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DISCUSSION

No questions were asked.

2.3 FOCUSED MGDS DESIGN AT THE YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

This was a verbal presentation by Mitchell G. Brodsky, Yucca Mountain Site Characterization Project, Las Vegas, United States of America (Note: Mr. Brodsky did not provide a paper for publication)

DISCUSSION

Glen McCrank, AECL

I was wondering given the variety of fuel types in the United States if you are going to need more than one multi-purpose container (MPC)?

Mitch Brodsky, USDOE

I would say absolutely. Approximately 20% of the expected waste will not be in standard form. We are looking at MPCs between about 75 tonnes and 125 tonnes. The mass of waste for disposal is in the neighbourhood of 89 000 Mg, so the answer to your question is definitely yes, it would have to be a family of containers.

Kam Tsui, Ontario Hydro

You mentioned about using the multiple design concepts process is your design approach. How many design concepts are you currently considering?

Kal Bhattacharyya, CRWMS M&O

Up until we adopted this focussed approach, we had seven waste package designs and a handful of repository designs. When you consider all of the ramifications for all of the design assumptions you have to make, the possibilities are almost endless, and they use a large amount of resources. The bottom line in design in that as long as we have the design approach that can meet the requirements, is cost effective, and takes into account alternative design features to enhance the waste isolation capabilities of an eventual repository we will have achieved our goal. There has also been limited funding from a budget standpoint. We have had the exploratory studies facility to pursue, the site characterization program to pursue, and there just isn't enough money to support a wide range of design alternatives for containers and repositories. You need to adopt a vision that can manage those kinds of changes, obviously that is one impact that you have to deal with.