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Monitoring during the stepwise implementation of the Swedish deep repository for spent fuel

Göran Bäckblom, Conrox

Karl-Erik Almén, KEA Geokonsult AB

March 2004

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

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Preface

As a consequence of the Research, Development & Demonstration Programme 2001, SKB initiated the project *Monitoring of the deep repository* to devise and share views on repository monitoring. This report is an account of the results of the project.

The Steering Committee members at SKB, Olle Olsson, Tommy Hedman and Stig Pettersson are acknowledged for their guidance. Several SKB employees provided information and background material for this report and the following persons are especially acknowledged for their contributions: Jan Carlsson, Tobias Lindborg, Olle Olsson, Stig Pettersson, Ignasi Puigdomenech, Marie Skogsberg, Christer Svemar, Lars Söderberg, Peter Wikberg and Ingemar Zellbi.

The work has benefited from discussions in the *Thematic Network on the Role of Monitoring in Phased Approach to Disposal* arranged by EU and the lead author recognises the ample opportunities for exchange within the network.

The report has been reviewed within SKB and others with special acknowledgements to Kimmo Lehto (Posiva) and Stefan Mayer (ANDRA).

Göran Bäckblom, Conrox

Karl-Erik Almén, KEA Geokonsult AB

Summary

As a consequence of the Research, Demonstration & Development Programme 2001, SKB initiated a project *Monitoring of the deep repository* to devise and share views on the repository monitoring. An important part of the project has been the active participation in the EU-project *Thematic Network on the Role of Monitoring in Phased Approach to Disposal* established to improve the understanding of the role of and options for monitoring within a phased approach to disposal and to identify how monitoring can contribute to decision-making, operational and post-closure safety, and confidence in safety. This report is prepared to present a framework for monitoring within the Swedish context. Monitoring in this report is defined as *"Continuous or repeated observations or measurements of parameters to increase the scientific understanding of the site and the repository, to show compliance with requirements or for adaptation of plans in light of the monitoring results."*

The international outlook from IAEA, OECD/NEA, CEC and some country-specific reviews presented in the report forms a necessary background to the Swedish monitoring framework. The international and national regulatory framework on monitoring advocates monitoring at all stages of the repository implementation with the limitation that the closed repository shall not be dependent on monitoring or maintenance for its safety. Any measures to monitor should either have a minor or negligible impact on repository safety, or that the measures result in an improvement of safety, compared with the situation that would arise if the measures were not adopted.

The implementation of the deep repository in Sweden is executed in phases where monitoring is an inherently integrated activity in the programme. The first phase is the site investigations when Primary Baseline conditions are established. During the following construction phase of the repository, detailed site characterisation continues in conjunction with construction of the access to the deposition area, construction of parts of the deposition area and the central service area. Monitoring is then used to track the changes to the previously established Primary Baseline conditions and distinguishing these imposed changes from natural variations or from other man-made influences. The monitoring results are used to increase the understanding of the site and the barrier functions, to show compliance with operating and environmental requirements and to feed information into the decision to proceed to next phase in the repository implementation. During the initial operation phase, around 200–400 canisters of spent fuel is emplaced and deposition tunnels backfilled. After up-dated evaluations, the phase of regular operation begin, where detailed characterisation, construction of the repository and waste emplacement are concurrent activities. The closure of the repository will take place when all spent fuel has been emplaced, i.e. in the latter part of this century.

Monitoring during the stepwise implementation of the repository is executed of several reasons mainly to:

- describe the Primary Baseline conditions of the repository site,
- develop and demonstrate understanding of the repository site and the behaviour of engineered barriers,
- assist in the decision-making process,
- show compliance with international and national guidelines and regulations.

Specific rationales for monitoring are to:

- obtain knowledge of undisturbed conditions in nature and their seasonal variations (baseline) in order to identify and evaluate the impact of activities related to the deep repository during different phases,
- obtain a better understanding of the function of the deep repository system to support the safety account and to test models and assumptions,
- monitor the environmental impact of the deep repository,
- provide evidence that the working environment is safe with regard to radiological and non-radiological effects,
- show that requirements on radioactive waste verification (safeguards) are fulfilled.

SKB has over a range of years accumulated extensive experience to monitor underground non-nuclear and nuclear facilities. The monitoring is concerned with bedrock conditions before and during construction and operation of the facilities, active design to engineer the underground facilities based on monitoring results during construction, the safe and environmental construction and operation of facilities. Experience exists from monitoring of the barrier function at SFR, the final repository for low – and intermediate level waste and at the Äspö Hard Rock Laboratory and monitoring for safeguard at CLAB, the interim storage for spent nuclear fuel. The know-how on monitoring relates to all aspects from design, installation, operation and maintenance to decommissioning of systems. Useful and feasible sensors and communication systems are available to monitor safety-relevant issues. Routines are available to ensure monitoring data are relevant, quality assured, traceable and transparent.

It is natural that the development of a monitoring programme is stepwise and closely tied to the major decision-points in the implementation programme for the deep repository. As an overall strategy it is vital that monitoring be well integrated into the general plans rather than being a separate activity. The ongoing site investigations with an inherently integrated monitoring programme clearly benefits from this approach. This report provides an overview of the features, processes and parameters that are collected during the site investigations to establish the Primary Baseline conditions for monitoring prior to the construction of the repository. It is also proposed that the monitoring programme should at least entail the following elements:

- objectives for the monitoring programme,
- scope for the monitoring (criteria for selection of issues to be monitored, identification of the properties, processes, phenomena and observable quantities to be monitored),
- identification on what methods to be used,
- operation of the monitoring system (identification of the duration and frequency of monitoring, including criteria for when monitoring may terminate, quality control and reporting results from monitoring, decision on trigger levels for actions, decisions on what actions should be pursued in case trigger levels are exceeded).

The site investigations in progress in Sweden essentially capture these elements in the investigation programme, but due to reasons of transparency it is however helpful that the present monitoring programme is further elaborated to clarify duration, frequency and criteria for terminating monitoring points. The current situation (March 2004) is reasonable due to the early stage of investigations and it is foreseen that the monitoring programme successively will be developed to meet the needs of the subsequent construction phase.

There are of course still many open questions to address with respect to monitoring, not the least concerning monitoring of the open repository to collect data to verify barrier performance before closing the repository. Repository performance and safety cannot be directly monitored, but it would be of great significance that key indicators are determined to constitute a basis for tracking the performance of the repository during the repository implementation.

Repository closure is a stepwise process from consecutively closing a deposition tunnel to closing one or several deposition areas before the whole repository is closed. It is possible that rationales for monitoring of the post-closure phase, such as verification of safeguard requirements, may develop. The extent of the post-closure monitoring programme will essentially be given by the decisions made at closure and it is appropriate that any decisions on post-closure monitoring are taken by the generation that is the decision-maker at the time of closure. While the responsibility for the repository is transferred to the State after closure it is then also needed to clarify the responsibility for execution of the post-closure monitoring.

Sammanfattning

Som en följd av SKB:s Forsknings-, Utvecklings- och Demonstrationsprogram 2001, påbörjades projektet *Långtidsobservationer* (monitoring) *för djupförvaret* för att formulera och dela tankar om frågan. En viktig del i projektet har varit deltagande i EU-projektet *Tematiskt nätverk om funktionen av långtidsobservationer vid stegvist genomförande av slutförvaring.* Nätverket startades för att öka förståelsen om den roll som långtidsobservationer kan spela och vilka alternativ som finns att tillgå vid stegvist genomförande av djupförvaret, samt för att urskilja hur långtidsobservationer kan bidra till beslutsprocessen, till säkerhet under driftskedet och efter förslutning och för tilltron till säkerheten. Denna rapport är framtagen för att presentera ett ramverk för långtidsobservationer inom det svenska avfallsprogrammet. Långtidsobservationer definieras här som *"Sammanhängande eller upprepade observationer eller mätningar av parametrar för att öka den vetenskapliga förståelsen av platsen och förvaret, för att visa att krav är uppfyllda eller för att anpassa planer till med hänsyn till resultat från långtidsobservationerna".*

En internationell översikt av arbeten inom IAEA, OECD/NEA och en landsöversikt för några utvalda länder presenteras som en nödvändig bakgrund till ett svenskt ramverk för långtidsobservationer. Det internationella regelverket, liksom det nationella svenska regelverket, förespråkar långtidsobservationer under alla steg i förvarsgenomförandet med begränsningen att det förslutna förvarets säkerhet inte ska vara beroende av långtidsobservationer eller av kommande underhåll. De mått och steg som vidtas för att genomföra långtidsobservationer, ska antingen ha en liten eller försumbar påverkan på förvarets säkerhet, eller medföra en förbättrad säkerhet, jämfört med situationen som skulle råda om inte observationer genomfördes.

Genomförandet av djupförvaret i Sverige sker i steg där långtidsobservationer är en väl integrerad aktivitet i genomförandeprogrammet. Det första steget är platsundersökningarna där primära jämförelsedata *(Primary Baseline)* sammanställs. Under bygg- och detaljundersökningsskedet fortskrider detaljerade undersökningar av berget samtidigt som tillfart till deponeringsområden, delar av deponeringsområden och centralområde anläggs. Långtidsobservationerna används då för att mäta förändringar i tidigare insamlade primära jämförelsedata och särskilja dessa från naturliga förändringar och andra mänskligt påverkade förändringar. Observationerna används för att öka förståelsen av platsen och barriärfunktioner, för att visa att ställda krav är uppfyllda och för att ge information inför beslutet att gå vidare till nästa steg i genomförande av förvaret. Under det inledande driftskedet deponeras 200–400 kapslar med använt kärnbränsle och deponeringstunnlarna återfylls. Efter förnyade utvärderingar inleds reguljär drift, där detaljundersökningar, utbyggnad och deponering sker som parallella aktiviteter. Förvaret försluts under senare delen av detta århundrade, när allt bränsle deponerats.

Långtidsobservationer under det stegvisa genomförandet av djupförvaret genomförs med flera syften, men huvudsakligen för att:

- upprätta primära jämförelsedata *(Primary Baseline)* för förvarsplatsen,
- utveckla och demonstrera förståelse av förvarsplatsen och ingenjörsbarriärernas beteende,
- bistå i beslutsprocessen,
- visa att krav ställda i internationella och nationella riktlinjer och föreskrifter är uppfyllda.

Specifika syften för långtidsobservationer är att:

- erhålla kunskap om ostörda förhållanden i naturen och dess säsongsvariationer för att urskilja och utvärdera den påverkan som djupförvarsaktiviteter får under olika skeden,
- stärka förståelsen av djupförvarssystemets funktion för att stödja säkerhetsredovisningen och för att pröva modeller och antaganden,
- kontrollera förvarets miljöpåverkan,
- ge underlag för kontroll av arbetsmiljön så att den är säker med hänsyn till radiologiska och icke-radiologiska effekter,
- visa att krav på kontroll av kärnavfall *(safeguard)* är uppfyllda.

SKB har under ett antal år samlat betydande erfarenheter från långtidsobservationer av kärntekniska och icke-kärntekniska anläggningar. Observationerna har rört bergförhållanden, före och under utbyggnad, under drift av anläggningarna, tillämpning av aktiv design under byggskedet så att observationer utnyttjas för detaljprojektering av anläggningen och observationer för säkert byggande och drift av anläggningarna. Erfarenheter hämtas från långtidsobservationer av barriärfunktioner vid slutförvaret för låg- och medelaktivt avfall, SFR och vid Äspölaboratoriet. Observationer för kontroll av avfall *(safeguard)* tillämpas vid mellanlagret för använt kärnbränsle, CLAB. Den förvärvade kunskapen om långtidsobservationer rör alla aspekter från design, installation, drift/underhåll till avveckling av mätsystem. Dugliga och användbara sensorer och datakommunikationssystem finns som registrerar faktorer av relevans för säkerheten. Rutiner finns tillgängliga för att trygga att data från långtidsobservationer är relevanta, kvalitetssäkrade, spårbara och tydliga.

Det är naturligt att utvecklingen av program för långtidsobservationer sker stegvis och nära knyts till de större beslutstidpunkterna i djupförvarets genomförande. I den övergripande planläggningen, är det väsentligt att långtidsobservationer är väl integrerade med de allmänna planerna hellre än att vara en fristående verksamhet. De nu pågående platsundersökningarna med ett väl integrerat program för långtidsobservationer gynnas klart av detta förfarande. Denna rapport ger en översikt av de egenskaper, processer och parametrar som samlas under platsundersökningarna för att skapa primära jämförelsedata för långtidsobservationer före det att byggskedet inleds. Det föreslås också att program för långtidsobservationer åtminstone bör innehålla följande:

- målen med programmet för långtidsobservationer,
- onfattningen (principer för val av spörsmål som långtidsobserveras, urskiljning av egenskaper, processer, fenomen och observerbara storheter som ska långtidsobserveras),
- bestämning av de metoder som ska användas,
- observationssystemets drift (fastställande av observationernas varaktighet och frekvens, liksom principer för hur mätningar kan avvecklas, kvalitetskontroll och rutiner för hur resultat från långtidsobservationer redovisas, bestämning av tröskelvärden *(trigger levels)* som kräver åtgärder),
- beslut om vilka åtgärder som ska vidtas om tröskelvärden överskrids.

De pågående platsundersökningarna i Sverige innehåller i huvudsak dessa element i platsundersökningsprogrammet, men det är av värde att det nuvarande programmet för långtidsobservationer detaljeras för att klarställa observationernas varaktighet, frekvens och principer för hur mätningar avvecklas. Den nuvarande situationen (Mars 2004) är rimlig, med hänsyn till att undersökningarna nyligen inletts och det förutses att programmet för långtidsobservationer successivt utvecklas för att möta behoven för det efterföljande bygg- och detaljundersökningsskedet.

När det gäller frågan om långtidsobservationer för djupförvaret finns det naturligtvis många återstående spörsmål att hantera, då inte minst när det gäller observationer under driftskedet för att säkerställa barriärfunktionerna innan förvaret förseglas. Förvarets funktion eller säkerhet låter sig inte observeras direkt, men det är av stort värde att fastställa huvudindikatorer *(key indicators)* för att följa förvarets utveckling under genomförandet.

Försegling av djupförvaret är en stegvis process från det att en deponeringstunnel försluts, tills dess att ett eller flera deponeringsområden försluts och sedermera innan hela förvaret förseglas. Det är möjligt att skäl till långtidsobservationer efter förslutning, som kärnämneskontroll (*safeguard*) kan framkomma. Omfattningen av observationer efter förslutning kommer dock i allt väsentligt att ges av av de beslut som fattas vid förseglingen och det är lämpligt att beslut om långtidsobservationer efter försegling fattas av den generation som är beslutsfattare då. Med hänsyn till att ansvaret för förvaret efter förslutning överförs till staten, är det då också nödvändigt att klarlägga ansvaret för att dessa observationer genomförs.

Contents

1 Introduction

Monitoring is standard practice in science since historical times. The Egyptians monitored the movements of stars, the sun, the moon and the rise and fall of the river Nile to establish a calendar with 365 days per year as early as 4241 BC /Boorstin, 1985/. Since then, monitoring has been used in all kind of science and technology to develop understanding, models, methods and design.

This report is on monitoring of geological disposal. Geological disposal is the preferred method for long term isolation of long-lived radioactive waste where the safety of the overall repository system is achieved through a combination of natural barriers and engineered barriers /OECD/NEA, 1995/. Many countries, as well as Sweden, are now well under way to implement deep underground disposal facilities in a stepwise manner where each major step is taken only after thorough examination of previous results and scrutiny of plans.

The Swedish solution, the KBS-3 method, is primarily designed to isolate the waste within the engineered barriers. If the isolation function should for any reason fail in any respect, a secondary purpose of the repository is to retard the release of radionuclides. This safety is achieved with a system of barriers Figure 1-1.

The fuel is placed in corrosion-resistant copper canisters. Inside the five-meter-long canisters, a cast iron insert provides the necessary mechanical strength. A layer of bentonite clay, surrounding the canisters, protects the canister mechanically in the event of small rock movements and prevents groundwater and corrosive substances from reaching the canister. The clay also effectively adsorbs many radionuclides that could be released should the canisters be damaged. The canisters with surrounding bentonite clay are emplaced at a depth of about 400–700 m below surface in crystalline bedrock, where mechanical and

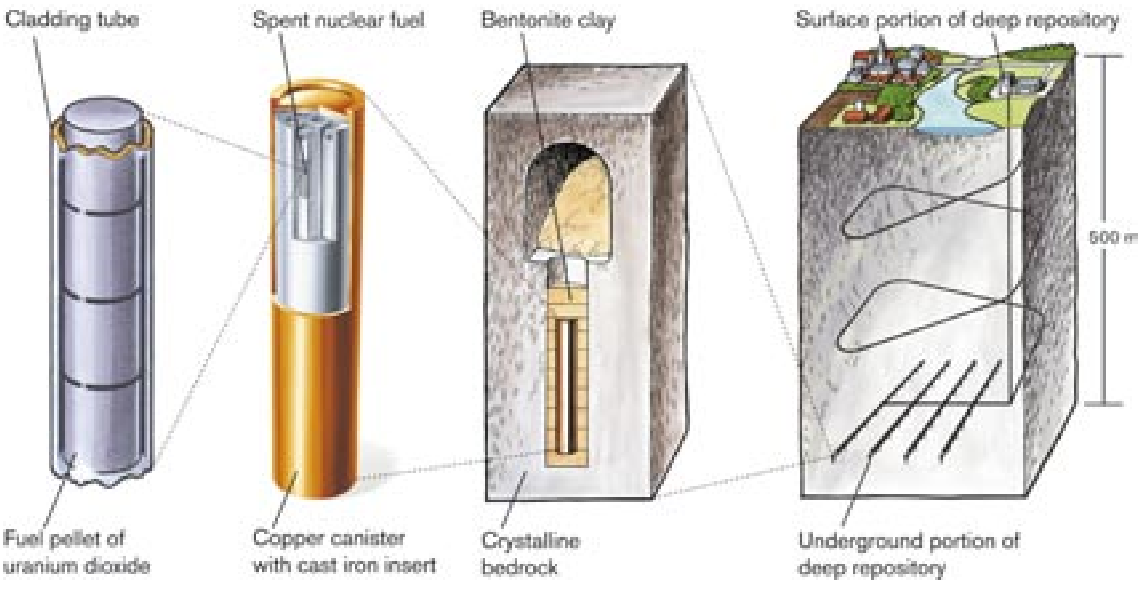

***Figure 1-1**. The KBS-3 system to safely dispose of spent nuclear fuel. The picture shows the KBS3-alternative when the canister is deposited vertically. SKB is also studying the feasibility of horizontal deposition of the canisters.*

chemical conditions are stable in a long term perspective. Should any canister be damaged, the chemical properties of the fuel and the radioactive materials, for example their poor solubility in water, put severe limitations on the transport of radionuclides from the repository to the ground surface. This is particularly true of those elements with the highest long term radiotoxicity, such as Americium and Plutonium. The repository is thus built up of several barriers, which support and complement each other. The safety of the repository must be adequate even if one barrier should be defective or fail to perform as intended. This is the essence of the multiple barrier principle.

The application of monitoring within the KBS-3 system has previously been addressed /Olsson et al, 2001/ with the views that:

- *"The repository shall not be dependent for its long term safety on monitoring or maintenance by future generations. This is not to say, however, that the repository cannot be monitored for a period after disposal of the waste or after the closure of the repository.*
- *Information regarding the waste, the disposal system and the site should be preserved for the future as well as can reasonably be achieved."*

The nuclear industry in Sweden has the responsibility for managing and disposing of all radioactive wastes from its plants. The owners of the nuclear power plants jointly formed Swedish Nuclear Fuel and Waste Management Co. (SKB) for this purpose. SKB is responsible for the implementation of the waste management system. The comprehensive program for implementation of the waste system is accordingly to the Act on Nuclear Activities, reviewed every third year based on the R&D program prepared by SKB. The fee levied on the producers of the electricity by nuclear power is decided yearly according to the Act on the Financing of Future Expenses for Spent Fuel etc. Several laws and regulations govern the work. Swedish Nuclear Power Inspectorate (SKI) and the Swedish Radiation Protection Agency (SSI) are the main authorities for safety issues related to built and planned nuclear facilities and radiation protection respectively. The regulatory framework for example stipulates /SKI, 1998/ that a facility for the final disposal of nuclear waste shall be designed *"so that the barriers can provide the required safety without monitoring or maintenance after the repository is closed.* SKI also requires /SKI, 2002/ that *"the impact on safety of such measures that are adopted to facilitate the monitoring or retrieval of disposed nuclear material or nuclear waste from the repository, or to make access to the repository difficult, shall be analysed and reported to the Swedish Nuclear Power Inspectorate"*. The regulations also advise: *"Measures can be adopted during construction and operation for the possible monitoring of a repository's integrity and its barrier performance after closure."* It is also advised that the safety report *"should show that these measures either have a minor or negligible impact on repository safety, or that the measures result in an improvement of safety, compared with the situation that would arise if the measures were not adopted"*.

The implementation of the deep repository is executed in phases c.f. Figure 1-2 and in each phase monitoring is a vital part of the programme. The site investigations provide the general setting and a baseline for the consecutive phases. During the construction phase detailed site characterisation continues in conjunction with construction of the access to the deposition area, construction of parts of the deposition area and the central service area. During the initial operation phase, around 200–400 canisters of spent fuel is emplaced and deposition tunnels backfilled. The initial operation phase is followed by the phase of regular operation phase where detailed characterisation, construction of the repository and waste emplacement is concurrent activities. The closure of the repository will take place when all spent fuel has been emplaced, i.e. in the latter part of this century. After the closure of the repository, we can anticipate two phases; one phase where institutional control is assumed

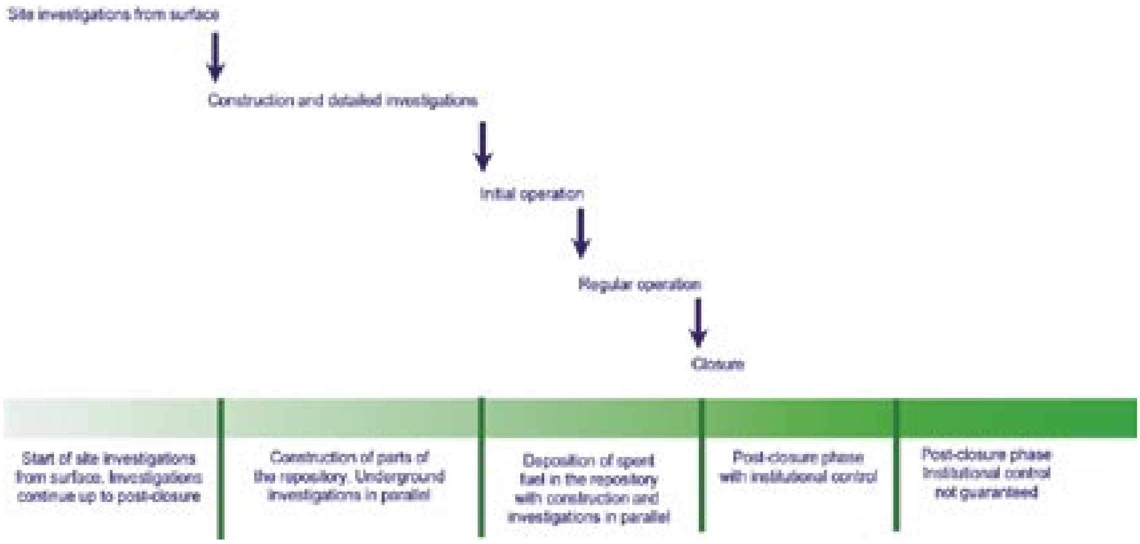

Figure 1-2. *Outline of phases in the step-wise implementation of the Swedish deep geological repository for spent fuel.*

and one phase where institutional control cannot be taken for granted. The legal responsibility for the deep repository will be transferred to the State after closure of the repository.

A good overview of the stepwise approach for implementation of the Swedish deep repository is provided in the Research, Development and Demonstration Programme 2001 (RD&D 2001) /SKB, 2001a/. Site investigations are in progress in two communities, Oskarshamn and Östhammar with the aim to apply for the siting and construction licence within a few years. Engineering, system analysis and optimisation are concurrent activities. The RD&D 2001 also calls for studies with respect to monitoring to:

- formulate an SKB policy on monitoring,
- determining the initial state and seasonal variations (baselines) at the sites in Oskarshamn and Östhammar,
- prepare preliminary monitoring programmes for the coming phase of construction and initial operation,
- follow international developments concerning the need for post-closure monitoring and institutional controls.

As a consequence of the RD&D programme, SKB initiated a project *Monitoring of the deep repository* to devise and share views on repository monitoring. An important part of the project has been the active participation in the EU-project *Thematic Network on the Role of Monitoring in Phased Approach to Disposal* established to improve the understanding of the role of and options for monitoring within a phased approach to disposal and to identify how monitoring can contribute to decision-making, operational and post-closure safety, and confidence in safety /CEC, 2004/.

This report is prepared to present a framework for monitoring within the Swedish context. Definitions and nomenclature are proposed and the present international and national framework presented. The report also describes the current plans for monitoring during the site investigation phase and outlines the foreseen monitoring during the subsequent phases in the repository implementation.

The preparation of the framework accounts from experience when monitoring the interim storage for spent nuclear fuel (CLAB), the final repository for low and medium-level waste (SFR), the previous site characterisation activities from the ground surface at several study-sites in the 80íes, the experiments at the underground research laboratories at Äspö Hard Rock Laboratory and as well from the ongoing site investigations at the candidate sites.

2 Definitions and nomenclature

The report /CEC, 2004/ clearly evidences that definitions and nomenclature used not are harmonised within the nuclear waste community. This is due to the existing country-specific legal context as well as different views on the role of monitoring in the stepwise implementation of geological disposal. This chapter provides a short account of some definitions and nomenclature in use before establishing the nomenclature adopted for this report. A suggested English-Swedish glossary is annexed in Table A-7.

2.1 Monitoring and its relation to site characterisation

The commonality of the definitions as presented in Table 2-1 shows that monitoring is tied to a purpose and that monitoring is an activity extending over a certain time. In the SKB definition adopted here we rule out single measurements or single observations as part of any monitoring programme. It is also implied that the repeated observations for monitoring occur at the same location (point or section). Surveillance of the repository and observations to satisfy safeguard requirements are included in the SKB definition. Monitoring can also be interpreted in a broad sense to include monitoring of science and society, but our position here is that repository monitoring is confined to the technical monitoring of the repository at a given site.

Monitoring can also be conducted in the broad sense to include monitoring of science and society, but the SKB position is that repository monitoring is confined to the technical monitoring of the repository at a given site.

Table 2-1. Overview of definitions of monitoring.

Definition of monitoring	Organisation	Reference
To watch, keep track of, or check usually for a special purpose		Merriam-Webster (www.m-w.co)
Continuous or periodic observations and measurements of engineering, environmental or radiological parameters, to help evaluate the behaviour of components of the repository system, or the impacts of the repository and its operation on the environment.	IAEA	/IAEA, 2001/
Continuous or periodic observations and measurements of engineering, environmental, radiological or other parameters and indicators/characteristics, to help evaluate the behaviour of components of the repository system, or the impacts of the repository and its operation on the environment, and to help in making decisions on the implementation of successive phases of the disposal concept.	CEC Thematic network on monitoring	/CEC, 2004/
Repeated measurements or observations during a longer period of time, generally extending over several stages of repository development.	SKB	/SKB, 2001a/
Continuous or repeated observations or measurements of parameters to increase the scientific understanding of the site and the repository, to show compliance with requirements or for adaptation of plans in light of the monitoring results	SKB	This report

Monitoring is pursued to increase the scientific understanding. Development of scientific understanding is inherently tied to testing and development of models and this goes also for increasing the scientific understanding of the geological disposal system and its evolution and safety over time.

Much effort is used to collect data to describe the current and future site conditions and it is important to understand the concept of monitoring in relation to the concept of site characterisation in model testing and development. SKB views monitoring as an integrated part of the site characterisation activities and in the following we explain what part of the site characterisation programme is treated as monitoring: SKB has developed a condensed description for models, to simplify a transparent overview of all models in use, Table 2-2 with a typical application in Table 2-3. In this context measurements, or observations concerned with the material properties of the constitutive equations are not considered a part of monitoring. Monitoring for purpose of model development then is mainly for tracking changes in "boundary conditions" and "output parameters".

Table 2-2. Condensed description of models /Gustafson, 1998/.

MODEL NAME	
Model scope or purpose Specification of the intended use of the model	
Process description Specification of the process accounted for in the model, Definition of constitutive equations	
CONCEPTS	DATA
Geometrical framework and parameters	
Dimensionality and/or symmetry of model. Specification of what the geometrical (structural) units of the model are and the associated geomterical parameters (the ones fixed implicitly in the model and the variable parameters).	Specification of the size of the modelled volume. Specification of the source of data for geometrical parameters (or geometrical structure). Specification of the size of the geometrical units and resolution.
Material properties	
Specification of the material parameters contained in the model (it should be possible to derive them from the process and the geometrical units).	Specification of the source of data for material parameters (could often be the output from some other model). Specification of the value of material parameters.
Spatial assignment method	
Specification of the principles for the way in which material (and if applicable geometrical) parameters are assigned throughout the modelled volume.	Specification ot the source of data for model, material and geometrical parameters. Specification of the results of the spatial assignment.
Boundary conditions	
Specifications of (type of) boundary conditions for the modelled volume.	Specification of the source of data on boundary and inititial conditions. Specification of the boundary and initial conditions.
Numerical or mathematical tool	
Computer code used	
Output parameters	
Specification of parameters and possibly derived parameters of interest	

Table 2-3. Example on concepts used to describe groundwater flow for natural and disturbed conditions /Rhén et al, 1997/.

GROUNDWATER FLOW OF THE ÄSPÖ SITE
Stochastic continuum model

Scope
Natural groundwater flow, flow to laboratory tunnel

Process description
Continuity equation (mass balance equation)
Equation of motion (Darcy´s law, including density-driven flow)
Equation of state (Salinity-density relationship)

CONCEPTS

Geometrical framework and parameters
Three-dimensional box divided into:
- hydraulic conductor domains. 2-D features (location, extent, orientation)
- hydraulic mass domains. 3-D features (location of boundaries)

Material properties
Hydraulic conductor domains: Transmissivity (T)
Hydraulic mass domains: Hydraulic conductivity (K)

Spatial assignment method
T: Deterministic assignment
K: log-normal distributions for hydraulic conductivity {K_g, s(Log_{10}[K])}
K and s are dependent on cell size within a domain in the numerical model

Boundary conditions
Upper: Fixed infiltration rate on Äspö, constant head at sea and peat areas
Lower: No flow
Side: Prescribed pressure (hydrostatic)
Salinity: Prescribed initial conditions, linear increase with depth at vertical boundaries
Tunnel: Hydraulic resistance (skin factor) around the tunnel and presrribed pressure (atmospheric) or flow rate into the tunnel

Numerical tools
Finite-volume code PHOENICS

Output parameters
Groundwater pressure
Groundwater flux
Salinity within the 3D calculation volume

2.2 Baseline conditions and its relation to the implementation phases of the repository

A baseline is "*a set of critical observations or data used for comparison or a control*" or a "*starting point"* accordingly to Merriam-Webster (www.m-c.com) and we understand here that a baseline can be a very broad concept, to fit with the broadest definition of monitoring.

Even if we can think of baselines prior to start of site investigations at the surface, we here define the Primary Baseline as *"site-specific conditions prior to start of construction of the repository (before going underground)"* and delimit the baseline to site conditions of potential interest for basic earth science, engineering, environment, operational and post-closure safety assessment of the repository. The broad aspect of tracking development of science, societal values etc are not included here.

In correspondence with the previous section, we also make a clear distinction between "*baseline conditions"* in general and "*baseline conditions for the purpose of monitoring*", Figure 2-1. The site description established before going underground contains a broad range of issues being the baseline for the subsequent phases and the baseline established for monitoring is a subset of the data collected during the site characterisation. The monitoring

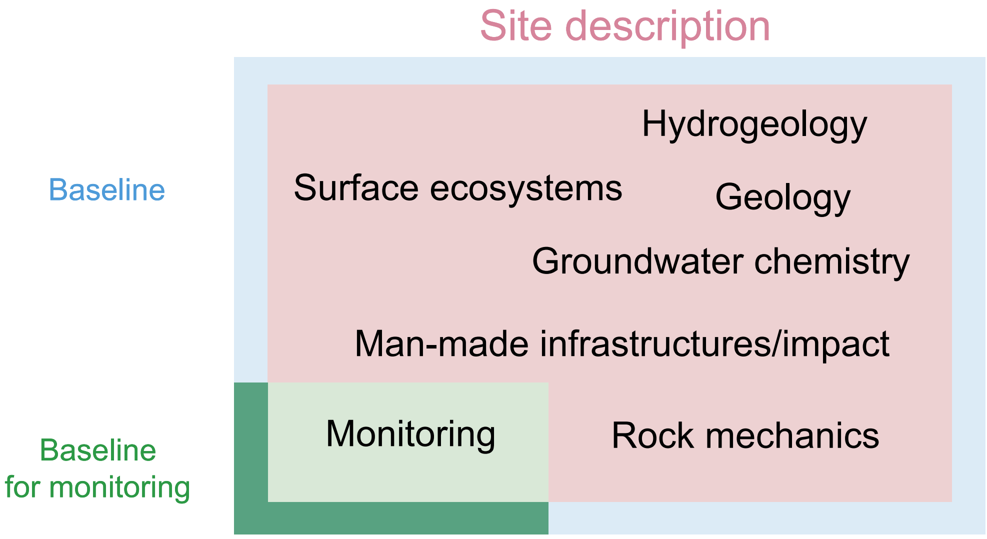

Figure 2-1. *Relation between site characterisation and monitoring.*

data are related to changes in state rather than description of material properties. From the SKB definition of monitoring we also rule out single measurements as part of the monitoring programme. An example follows: One issue in the site investigations is to locate major fracture zones and define the lengths, strikes, dips and widths of the zones. As these fracture zones were generated maybe hundred of million of years ago we cannot expect any changes in geometry over next few hundred years. Therefore whilst the geometrical description and its subsequent updating is a part of the site characterisation programme, it is not a part of the monitoring programme, as the geometry is not monitored continuously or by periodic observations.

From Figure 2-1 we may understand that the site description contains 1) a baseline for monitoring that is used to track changes of state and 2) a general baseline produced in the site description. The latter baseline is used, not to track changes of state but to track the differences (of "material properties") in the consecutively updated site descriptive models. The baseline conditions established before going underground with construction of the repository – the Primary Baseline – is in analogy with Table 2-2 the "initial conditions".

The general idea of establishing the baseline conditions for monitoring is to create a set of reference data, against which the changes caused by repository development can be recognised and distinguished from natural and other man-made temporal and spatial variations in the repository environment.

It is expected that updated initial conditions, e.g. new baselines are required at later stages, e.g. before the closing and sealing the repository even if these baselines are based on "disturbed conditions". It would – in principle – be possible to establish new baselines at every phase in the repository development, the time-zones of a disposal concept as in the CEC-project on retrievability being the most ambitious /Grupa et al, 2000/ updating sequence. There is yet no terminology in use for naming the subsequent baselines that may be established in the course of the implementation following the Primary Baseline. It is foreseen that the transition from one phase to the next phase (Figure 1-2) are natural and excellent timing for establishing updated baselines if found necessary.

Note that the waste and its properties not are a part of the monitoring programme (besides safeguard), as the deliveries of spent fuel will be based on a waste classification and waste acceptance documentation.

3 Outlook

This chapter reviews some pertinent information as a backdrop to the later chapters of the report. Work in IAEA, OECD/NEA and CEC is examined and followed by a review of the country-specific conditions in Canada, Finland, France, Japan, Switzerland and USA. The general SKB experience of monitoring is also presented.

3.1 International Atomic Energy Agency (IAEA)

IAEA published a discussion document on monitoring of geological repositories for high-level radioactive waste /IAEA, 2001/ examining possible purposes for monitoring at the different stages, the potential use of information and techniques that may be applied. The monitoring is discussed in the context of seven stages in the repository plans: 1. Surface exploration. 2. Access construction and underground exploration. 3. Construction of the repository. 4. Emplacement of waste and near-field engineering barriers. 5. Disposal tunnel/Vault backfilling. 6. Backfilling of remaining openings and repository sealing. 7. Post-closure. The report concludes that monitoring a deep geological repository and its environment would be carried out as an aid to decision-making, particularly to move from one operational stage to another in the management of the facility. An important aspect of monitoring during the operational phase and any subsequent pre-closure period is to enhance understanding of those aspects of the safety case that are feasible to address over a period of several decades.

An important IAEA-work in progress /IAEA, 2004/ is the Safety Standard on Geological Disposal of Radioactive Waste. The IAEA's safety standards are not legally binding on Member States but may be adopted by them, at their own discretion, for use in national regulations in respect of their own activities. The standards are binding on the IAEA in relation to its own operations and on States in relation to operations assisted by the IAEA.

From the draft Safety Standard we excerpt that:

"[2.4] Disposal is taken to mean the emplacement of waste in an appropriate facility without the intention of retrieval. Geological disposal facilities are designed to ensure long term safety through the passive protection provided by engineered and geological barriers, not relying on monitoring or institutional controls after the facility is closed. This does not mean that the waste could not be retrieved, or that monitoring could not be carried out, if this or future generations choose to take such actions. It is likely that institutional controls will be applied for a period after closure of a geological disposal facility, for example, to provide a framework for longer term monitoring, to prevent inadvertent disturbance of the facility, and for the purposes of nuclear safeguards."

"Requirement 21: Monitoring programmes

A programme of monitoring shall be defined and carried out prior to and during the operation of the disposal facility. This shall be designed to confirm the conditions necessary for the safety of workers and members of the public and protection of environment during the operation of the disposal facility and to confirm the absence of conditions that would undermine the long term safety of the disposal facility."

"[5.29] Monitoring will be required during each step of disposal facility development. Purposes may include providing baseline information for later assessments, assurance of operational safety and facility operability, and measurements to confirm conditions consistent with long term safety. The latter includes shaft and tunnel stability, control of drainage water, control of underground air conditions, operability of waste handling and other equipment, and radiological control. Monitoring programmes must be designed and implemented so as not to reduce the overall level of long term safety. [5.30] A discussion of monitoring related to long term safety of disposal facilities is given in reference /IAEA, 2001/. Plans should be drawn up before construction of the disposal facility to indicate possible monitoring strategies, but these should remain flexible and if necessary revised and updated during the development of the facility."

"Requirement 22: Nuclear safeguards

Nuclear safeguards requirements shall be considered in the design and operation of disposal facilities to which nuclear safeguards apply, and shall be implemented in such a way as not to unduly reduce the long term safety. [5.32] In practice, nuclear safeguards for a closed disposal facility might be achieved by remote means, e.g. satellite monitoring, microseismic surveillance and administrative arrangements. Intrusive methods, which might interfere with long term safety, must be avoided. Continuation of safeguards, since they will, in some instances, be internationally supervised, may increase the confidence in longevity of administrative controls that would also prevent inadvertent disturbance of the disposal facility. Continuation of safeguards and monitoring after closure may thus be beneficial to confidence in the long term safety."

The IAEA document recognises the benefit of monitoring for moving from one operational stage to the following and also fully acknowledges the importance of monitoring the operational safety of the nuclear facility. However with respect to long term safety, results of monitoring are not intended to optimise the repository design, rather to confirm the absence of conditions that would undermine the long term safety of the disposal facility. Work is also in progress to develop guidelines for handling the safeguard aspects of a geological repository /IAEA, 2003/.

Sweden has also signed the "Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management" with IAEA being the secretariat /IAEA, 1997/ where it is stated *"operation, maintenance, monitoring, inspection and testing of a spent fuel management facility are conducted in accordance with established procedures". For a disposal facility the results thus obtained shall be used to verify and to review the validity of assumptions made and to update the assessments as specified […] for the period after closure.*

3.2 OECD/NEA

The Organisation For Economic Co-Operation And Development (OECD) with its Nuclear Energy Agency (NEA) regularly publishes Policy Papers jointly produced by authorities and industry.

In the choice between a geological disposal and indefinite storage and monitoring it was deemed unethical to plan for the latter as it would be unethical to pass responsibility for real action to future generations /OECD/NEA, 1995/. On the other hand, although geologic disposal is conceived as a passively safe arrangement, with no requirement for long term control, the concept does not preclude monitoring and maintenance of a repository by this and future generations. Society may choose to implement long term institutional controls, including protection of the site and monitoring /OECD/NEA, 1999/.

In the Policy Paper on reversibility and retrievability /OECD/NEA, 2001/ it is argued that the plan for monitoring related to performance should be carefully considered and reasoned arguments applied so that the relevance of measured parameters to eventual long term safety is known. It is also recognised that an extended open period between waste emplacement and repository closure will modify site conditions and delay or prevent the conditions that are aimed at for long term safety. It is further suggested that during the operational period, and any extended open period that follows it, monitoring of rock stability, the underground environment, and waste package conditions will be needed. The results of monitoring will be used to plan maintenance and refurbishment of the various systems and underground elements. The results may also contribute to decisions on when to move to the next stage towards repository closure, as they will refine estimates of how long a given stage can be maintained without significant additional expenditure on maintenance and refurbishment. They may prompt backfilling of some underground openings, if it is revealed that an extended open period may lead to effects that could compromise long term or operational safety. Subsequent monitoring, which may include the monitoring of backfill conditions, may be carried out to follow the early evolution of the engineered barriers, and to check that the expected evolution towards stable physical and chemical conditions is underway.

3.3 European Union

The European Atomic Energy Community (EURATOM) codified the EURATOM Treaty in Rome 1957 (http://europa.eu.int/abc/obj/treaties/en/entoc38.htm) where some of the articles are of relevance for monitoring (Article 35, 36, 37):

[Article 35] "*Each Member State shall establish the facilities necessary to carry out continuous monitoring of the level of radioactivity in the air, water and soil and to ensure compliance with the basic standards. The Commission shall have the right of access to such facilities; it may verify their operation and efficiency",* [Article 36] "*The appropriate authorities shall periodically communicate information on the checks referred to in Article 35 to the Commission so that it is kept informed of the level of radioactivity to which the public is exposed",* [Article 37] *"Each Member State shall provide the Commission with such general data relating to any plan for the disposal of radioactive waste in whatever formas will make it possible to determine whether the implementation of such plan is liable to result in the radioactive contamination of the water, soil or airspace of another Member State."*

In Sweden, the Swedish Radiation Protection Agency (SSI) is the responsible organisation for reporting in accordance with the Treaty. However it is not likely the Treaty will become a part of the EU constitution.

It is apparent that there is a pan-European institutional control with respect to health & safety aspects that have been in place for close to 50 years and it is here presumed that the Treaty may be used for post-closure institutional control of geological disposal as well, if so decided.

The Commission of European Countries (CEC) has also for a number of years conducted R&D within the field of radioactive waste management. In the work on retrievability – *"the ability provided by the repository system, to retrieve waste packages for whatever reason retrieval might be wanted"* – /Grupa et al, 2000/, it was recognised that a repository development programme is likely to involve a wide-ranging programme of monitoring to demonstrate compliance with national or international regulations and to assist in the societal decision-making process. The report further puts forward that the issue of retrievability is closely tied to monitoring, even if there are reasons for providing retrievability that are unconnected to monitoring, for example to provide options for future generations. It is deemed that monitoring can serve retrievability in three ways by monitoring of parameters and data that:

- track the easiness to retrieve the waste,
- delay closure of deposition cells, tunnels, access,
- demonstrate the fitness of systems to retrieve the waste.

It was also acknowledged waste package monitoring would be impractical and that integrity is more likely to be obtained by control of container material, fabrication and environmental conditions in the repository. With good QA-procedures to show that the packages meet specifications, it would suffice to monitor the package environment after emplacement.

As a corollary of the concerted actions on retrievability, CEC arranged a thematic network on the role of monitoring in a phased approach to disposal with participants from ten European countries /CEC, 2004/. The objectives of the network was to improve both the understanding of the role of and the options for monitoring within a phased approach to the deep geological disposal of radioactive waste and to identify how monitoring can contribute to decision-making, operational and post-closure safety and confidence in safety. The subject of monitoring was perceived as one of increasing importance in repository programmes and also suitable for international collaboration. This increased importance arises from the move in several waste management programmes from concept development and research towards actual site investigation and implementation stages during which monitoring programmes must be defined, the recognition of the need for well-founded decision bases and evidence (to which monitoring will contribute) in progressing phased geological disposal projects and the issues of confidence and how to develop it, especially in wider stakeholder groups including the public.

The study on monitoring was separated in monitoring for baseline conditions, for compliance, for evaluations and assessments of repository performance and monitoring in the broader sense, to periodically determine the status of important scientific, technical and societal issues to long term waste management. The work within the network really evidenced that the monitoring strategy so far is country-specific and closely linked to the country-specific disposal implementation plan, see examples in section 3.4. It was also recognised that monitoring is a question of balancing the benefits of gaining information on the behaviour of certain components of the disposal system against the possible detriments that might accrue as a result of this monitoring. The potential detrimental effects of monitoring activities could be, for example, the degradation of materials resulting from the delayed emplacement of engineered barriers, the formation of pathways through the barrier system leading to the enhanced flow of groundwater within the repository, an increased likelihood of human intrusion – especially if the underground structure remains open and society looses interest in institutional control and the introduction of a greater number of stray materials into the disposal areas (for the same reasons as mentioned above). A concluding remark from the network is that the extent of monitoring that is either appropriate or useful to implement is a sensitive question and depends on implementation strategies.

3.4 Country-specific information

This section describes some countries deliberations on monitoring of a geological repository.

3.4.1 Canada

The AECL Environmental Impact Statement for geological disposal in Canada /Allen et al, 1997/ advocated "the observational method" as a key tool for adaptation of plans to reality including an extensive monitoring programme encompassing the performance of waste packages and plugs in test areas in the repository, activities and processes at the disposal facility, the atmospheric and aquatic effluent streams leaving the disposal facility, the natural environment, including drinking water and locally produced food in the vicinity of the disposal facility, characteristics of the groundwater, such as pressure, temperature and concentrations of potential contaminants and environmental indicators, characteristics of the rock, such as permeability, stress and temperature, seismicity and socio-economic conditions. The programme would be defined in consultation with regulatory agencies and potentially affected communities. The monitoring results would help to establish baseline conditions, to obtain data to assess potential environmental effects, to improve understanding of the performance of the disposal system, to determine compliance with requirements in legislation, regulatory documents and guidelines, to develop repository design and to determine whether methods for monitoring, assessing, or managing environmental effects needed to be modified, and if so, how.

An important part of the repository plans was to construct a Component Test Area at the repository site. A series of physical materials property tests, technology demonstration and performance assessment tests would be conducted in the component test area(s) to provide information on the short-term in situ performance of the specific site. The tests would be started during the repository construction stage and be performed, monitored and analysed over the entire period during which the repository would be open /Simmons and Baumgartner, 1994/.

The report /Cooper et al, 1997/ provides an admirable overview of monitoring methods and techniques for all aspects of monitoring a geological repository. The authors recognise potential developments by fibre optics but anyhow conclude that post-closure monitoring of the disposal vault would be impractical for two reasons: 1. Conduits and cables leading from instruments would present potential pathways for contaminant release. 2. Instruments would fail in less than 100 years, due to metal corrosion and moisture absorption of polymer insulators.

3.4.2 Finland

Posiva has identified Olkiluoto as the candidate site for the Finnish spent fuel repository. As part of the necessary site investigations, an underground rock characterisation facility (URCF) known as ONKALO, will be built, with construction planned to commence in 2004. If investigations underground subsequently prove the site to be a suitable host for the repository, a licence application will be submitted around 2010, with repository construction commencing in 2012.

The report /Posiva, 2003a/ provides an overview of the Finnish monitoring programme in connection with construction and operation of the ONKALO facility. According to the general safety requirements for final disposal of spent fuel, disposal shall be planned so that no monitoring of the disposal site is required for ensuring long term safety and so that retrievability of the waste canisters is maintained to provide for such development of technology that makes it a preferred option. According to the guidelines provided by the Finnish authority STUK, facilitation of retrievability or potential post-closure surveillance activities shall not impair the long term safety. Whether monitoring activities during the operational period of the repository also will be applied to the engineering barrier system and the waste itself is still to be determined. It is understood that the requirements and possibilities for post-closure monitoring will be considered by the generations who are active when that time is approaching and will also depend on social conditions and development of technology. The possible needs for safeguards monitoring are currently under consideration both nationally and internationally.

Before starting the construction of ONKALO, Posiva will establish the baseline (undisturbed) conditions at Olkiluoto on the basis of data and information from surface investigations and deep boreholes. The report by /Posiva, 2003b/ is such a record of the baseline conditions. The monitoring programme is right now focused on monitoring changes in bedrock conditions. The report by /Miller et al, 2002/ suggests the following processes to be of high significance for repository performance and monitoring during the ONKALO construction:

- **Physical processes** – Development of an excavation damaged zone (EDZ), reactivation of existing fractures in the rock mass, generation of new fractures in the rock mass, aeration of the rock mass, planned introduction of foreign fluids and solid materials, isostatic uplift.
- **Hydrogeological processes –** Evolution of hydraulic network, hydraulic heads and fracture properties, density-driven flow, evolutions of the saline water interface.
- **Geochemical processes –** Evolution of fracture-coating materials and the rock matrix, leaching of rock spoil, influences of groundwater mixing and water-rock interactions and microbial activity, oxidation and carbonation of groundwater, influences of planned introduced fluids.
- **Biological processes –** Perturbation of microbiological populations and activities, biodegradation.

3.4.3 France

Driven by law and governmental requirements, the French program has adopted a reversible approach towards deep geologic waste disposal. This approach – while comparable to other international programs in its need to perform site selection, site characterisation, design of a robust concept and demonstration of a safety case before applying for a construction and operation licence – acknowledges current limits of scientific knowledge and preserves the right of future generations to choose, and possibly re-direct waste management options. It requires that a repository program be managed in a flexible and modular manner, allowing future generations to decide upon its progress. Each decision should be informed, and therefore monitoring of the repository is considered an essential component of the reversible approach /CEC, 2004/.

The evolution of relevant processes and repository component properties would be monitored during a pre-closure period whose duration cannot be specified a priori. The time scale considered is on the order of centuries. The information gathered through such monitoring activities could eventually support future decisions on whether to proceed towards closure of the repository. Alternatives may require retrieval of waste. Similarly, while the design presented before construction of the first module is robust, it cannot be precluded that future decisions require design modifications of as yet to be constructed waste modules.

The monitoring program is likely to evolve with the steps in the phased approach, due to the possible evolution of key phenomena to be monitored at different phases, to limitations imposed by technical feasibility of monitoring, and to constraints imposed by the need for ensuring passive long term safety of the repository. The reasons for monitoring in support of a reversible disposal process are to provide knowledge on the major phenomena which control the state and the evolution of the components of the disposal system and characterise this state at each step of the disposal process, to compare these data with existing knowledge of the evolution of the repository, to contribute to the stepwise management (decision-making) of the facility by assessing the knowledge of phenomena that occur in the current disposal phase, increase the confidence in this knowledge: thermal, mechanical, hydraulic, chemical, radiological processes, at various scales and in different locations, by assessing the practical conditions in which the disposal process might be reversed and the disposed packages retrieved and by modelling the future evolution of the system, as a function of the decision to be taken – keep the facility at the present stage, go through the next step of the disposal process, or reverse the process. In addition, the facility will be monitored during its construction and operation with regard to industrial availability and maintenance of the structures and operating equipment and safety and protection of workers and environment: fire detection, air quality, temperature, dose rates etc.

3.4.4 Japan

The H-12 project was conducted to establish a technical basis for geological disposal in Japan /JNC, 2000/. The implementation of the repository is planned in five stages, site characterisation, construction, operations, closure and post-closure stage. Monitoring is executed for the geological conditions around the engineered barrier system and the disposal facility, for environmental reasons and for the protection of workers. The number of boreholes and measurement items will be kept to a minimum not to perturb the disposal site more than necessary. The monitoring results from the operational stage – perturbations and responses in thermal, hydrogeological, geochemical and rock mechanical characteristics – will be used as a technical basis for deciding when to backfill the connecting and access tunnels for repository closure.

3.4.5 Switzerland

In Switzerland, no official or formal universal definition for monitoring does exist nor any present nuclear legislation with explicit requirements on monitoring. However any measures which would facilitate surveillance and repair of a repository or retrieval of the waste shall not impair the functioning of the passive safety barriers /CEC, 2004/.

The Swiss expert group on disposal concepts for radioactive waste – EKRA, has proposed a concept of "monitored geological disposal" where after emplacement of the wastes a period of monitoring will take place before closing the facility. The idea is first to construct a *test facility* that can be viewed as a site-specific Underground Research Laboratory (URL). When the pertinent information has been collected, in so far as this information is not readily available from surface site characterisation, construction of the *main facility* and the *pilot facility* may commence. The pilot facility contains a small but representative fraction of the waste, to provide information on the behaviour of the barrier system and to check predictive models and would also serve as a demonstration facility to provide input for decisions regarding closure of the entire facility. In addition, the pilot facility should allow early detection of any undesirable system evolution. It is foreseen that the pilot facility will be backfilled and sealed without delay, in order that it is in a state that represents as closely as possible the foreseen final state of the repository. It will, however, be monitored from a series of observation boreholes with the possibility also to carry out non-destructive or destructive sampling. The pilot facility and its access routes are arranged in such a way that the facility can continue to be monitored for a long period after closure of the main facility, c.f. Figure 3-1. The majority of the waste is emplaced in the *main facility* that also may be monitored for en extended period of time before closure.

As a comment here it is clearly demonstrated that the waste implementation plan and monitoring strategy are closely linked as the waste management plan is based on a cautious and stepwise collection of data and facts, including the monitoring data. It is evident that the monitoring strategy is one of the vehicles for the overall optimisation of the repository system and its implementation.

3.4.6 USA

The Waste Isolation Pilot Plant (WIPP) for transuranic waste is operating under institutional control. Monitoring of groundwater conditions etc is ongoing to establish background groundwater quality and monitor indicator parameters and waste constituents that provide a reliable indication of the presence of any hazardous constituents in the ground water.

The permit includes a post-closure plan /USDOE, 2001/ which describes activities required to maintain the Waste Isolation Pilot Plant (WIPP) after completion of facility closure. The "post-closure care period" begins after completion of closure of the first (of several) underground hazardous waste disposal unit and continues for thirty years after final closure of the facility. During the post-closure period, the WIPP shall be maintained in a manner that complies with the environmental performance standards applicable to the facility.

Once a facility is decommissioned, actions (referred to as "active institutional controls") will be taken to assure proper maintenance and monitoring. The Environmental Protection Agency (EPA) has specified that active controls will be maintained for as long as

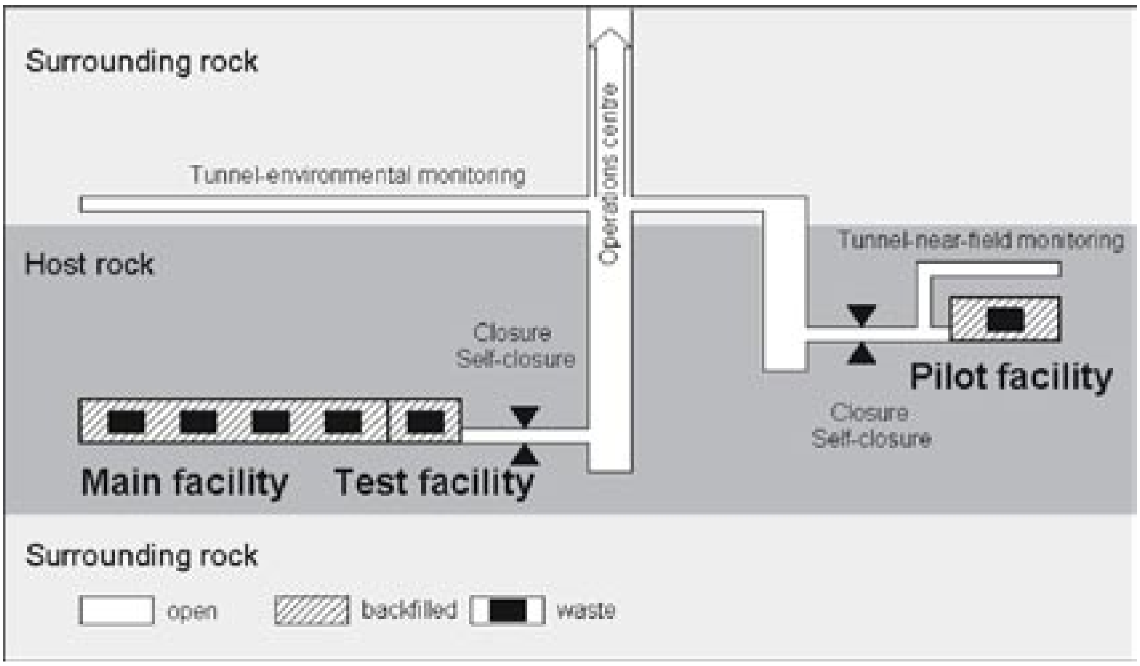

Figure 3-1. *Schematic representation of a generic repository facility accordingly to the EKRA-concept /CEC, 2004/.*

practicable and that no more than one hundred (100) years of active institutional control can be assumed in predictions of long term performance. This assumption assures that future protection and control does not rely on positive actions by future generations. The active institutional control program has a primary objective of addressing all applicable requirements, including restoring the WIPP site as nearly as possible to its original condition, and thereby equalising any preference over other areas for development by humans in the future. Post-closure groundwater monitoring will involve a continuation of the monitoring plan in the permits, but the sampling frequency may be changed as approved. The permits do not cover plans for passive institutional control after the active institutional control period is closing.

3.5 Experience of monitoring within the Swedish waste management programme

SKB has over the years acquired substantial experience to monitor the performance of nuclear and non-nuclear facilities including for example surface ecosystems, bedrock conditions, barrier performance, operational and environmental aspect as well as safeguard issues.

In this chapter experience from construction and operation of the interim storage facility CLAB, the final repository of operational waste with short and medium half-life, SFR and the Äspö Hard Rock Laboratory are discussed to provide examples of currently ongoing monitoring programmes. The Figure 3-2 depicts the CLAB and the SFR-facility.

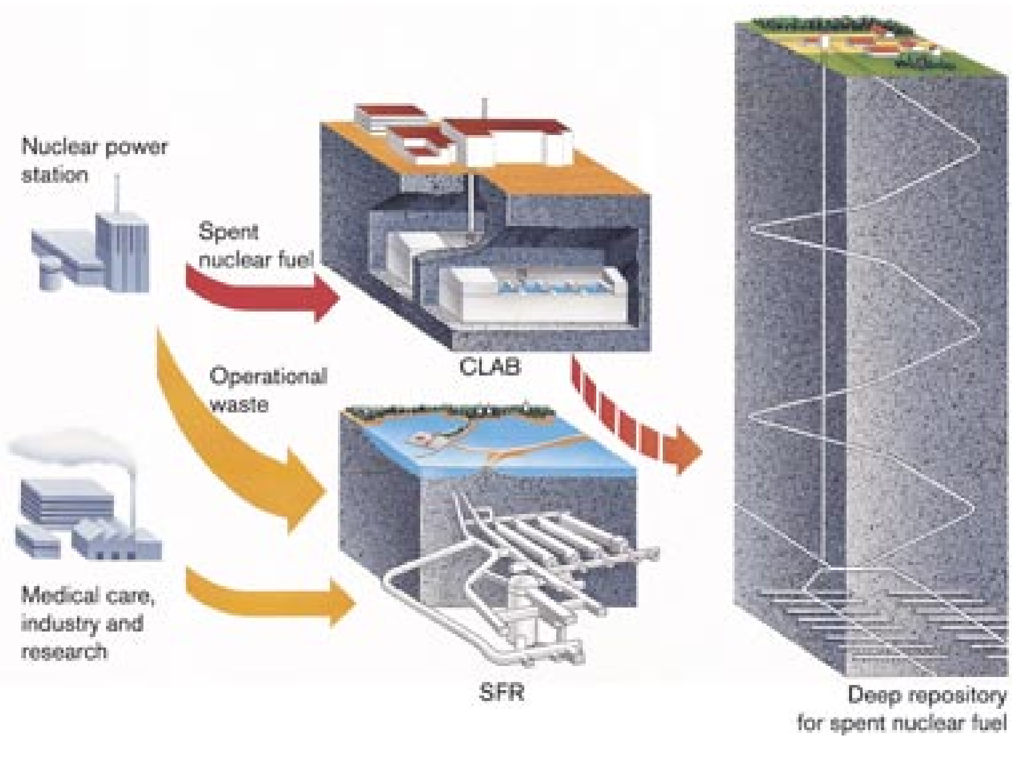

Figure 3-2. *Spent nuclear fuel (red arrow) is stored in the central interim storage facility CLAB 30–40 years before disposal in the deep repository. CLAB has been in operation since 1985. The second cavern shown will be in operation 2004. Operational waste from reactors and other sources (yellow arrows) are deposited in the final repository SFR. SFR has been in operation since 1988.*

3.5.1 Monitoring of the CLAB-facility

CLAB is an interim storage facility for all spent fuel in Sweden located close to the Oskarshamn nuclear power plants. The CLAB-1 cavern is excavated in granitic rock 30 m below the surface. The width of the rock cavern is 21 m and the height 28 m with a total volume of 63 000 m^3. The spent fuel is stored in deep pools of water installed in the underground caverns. The licensed storage capacity in CLAB-1 is maximum 5 000 tonnes of spent fuel correspondent to approximately 20 000 Boiling Water Reactor-elements and 2 500 Pressure Water Reactor-elements. Incoming deliveries are around 200 tonnes per year with 3 880 tonnes in storage early year 2003. Around 100 full-time staff operates the facility.

Experience from operating the CLAB-1 facility has been documented in an As Operated Safety Analysis Report /SKB, 1997/ that is required for every 10 year of operation. Typical monitoring includes integrity of water pools, concentration of contaminants in the pools, releases of any contaminants to atmosphere and water and radiation exposure to the staff. The facility caverns are regularly inspected and measurement results compiled. The facility is monitored with respect to fires and safeguard, the latter being a part of the physical protection system[1] required by SKI for the operation of any nuclear facility /SKI, 1998/. Occupational safety is enhanced by regular safety inspections.

The monitoring results from radiation protection and chemistry are reported on a monthly basis. An annual environmental report containing information on consumption of energy, groundwater, boreholes and waste compiled and submitted to the County Administration being the responsible authority. Annual operational reports are submitted to SSI and SKI as well. The monitoring programme for the integrity of the rock caverns and the water pools are updated every 4th year when the results are compiled in a summary report.

A second cavern – CLAB-2, with same storage capacity as the first cavern is under construction with start of operation during year 2004, Figure 3-3. The excavation of the cavern was a sensitive task, as the distance between the caverns is less than 40 m and the drill & blast excavation should not in any way disturb the safe operation of the existing nearby CLAB-1 facility. Before the construction started, SKB was by the permit required to prepare a monitoring programme for the excavation work, to be approved by SKI before start of the work. It was also required that any planned changes that may have safety implications would be reported to SKI for approval before execution of the change.

Monitoring of the excavation work included for example measurements of volume and chemistry of drainage water, of noise, dust and gases, of Peak Particle Velocities (PPV) from blasting and mechanical deformations of the caverns, pools and cranes. Threshold values for the PPVs were conservatively assigned, whereas threshold values for the deformations were defined from models with "best-estimates" of rock stresses and material model parameters. These threshold values were later assigned as "Alarm Threshold Level 2" with an "Alarm Threshold Level 1" being 75% of Level 2 to provide an early warning. The Level 1 value was however reached during the excavation work, but the consequences of hitting a Level 1-value was not anticipated. In accordance with routines, the local authorities were informed of the Level 1 being reached and mass media served an appropriate alarm-story concerning the excavation work when indeed it was intended as an internal alarm to change blasting routines. The same applied for the deformation measurements being predicted as best-estimates rather than alarm threshold values.

[1] i.e. "engineered, administrative and organisational measures which aim at protecting facilities against unauthorised intrusion, sabotage or other such impacts which can result in a radiological accident as well as at preventing the unlawful possession of nuclear material or nuclear waste."

Figure 3-3. Picture from construction of the CLAB-2 cavern, where monitoring data were used to adapt the excavation work to the rock conditions and to check compliance with requirements.

An important lessons-learned is the prudence required to assign threshold values that are really relevant for safety. The issue was later explored further, based on the CLAB-experience /Olsson and Stille, 2002/. The alarm threshold level is suggested to be defined as *"a pre-determined value of one or a combination of several monitored parameters which, if exceeded, will trigger pre-determined measures to prevent damage"*.

The equipment used for measurements of vibrations and deformation (extensometers, vibrating wires and precision surveying) has been well functioning and reliable.

3.5.2 Monitoring of the SFR-facility

SFR, the Swedish final repository for low-and intermediate level radioactive waste is a facility built under the seabed covered by 60 m of bedrock. The location below the seabed ensures a very small hydraulic gradient and prevents drinking water wells to be drilled into the repository for at least 1000 years, while the sea covers the area. The rock cavern for the most radioactive intermediate level waste is a 70 m high silo with the diameter of 30 m. For waste containing smaller amount of radioactivity, four rock caverns with length 160 m and 14 to 18 m in width and 9.5 to 16.5 m height are used, The disposal capacity is 63 000 m^3 with incoming deliveries of around 1000 m^3/year, Figure 3-4. Current volume disposed of at the beginning of the year 2003 is around 29 000 m^3. The staff for operation and maintenance is equivalent to approximately 12 man-years.

Following site investigation and licensing procedure a construction permit was granted. During the construction of the facility, SKB carried out a comprehensive monitoring and investigation programme to collect information needed to adapt the engineering to rock conditions at hand, to prepare the final safety analysis report needed to start operation and also to gather information to be used for preliminary design of sealing and decommissioning. The monitoring included groundwater pressures, sampling and analyses of seepage water and groundwater in fracture zones close to the caverns, deformation measurements of rock movements during and after construction and control of rock support. The operating licence was granted in 1988 with the first disposal in April the same year. A limited disposal in the silo began in January 1989. After some additional investigations the full licence for the silo was granted in the year 1991.

A monitoring programme has been in force since start of operation with the objectives to collect information for updated operational and long term safety analyses needed to operate and close the facility. The monitoring programme consists of a general framework programme with sub-programmes for monitoring the rock (rock support with non-destructive bolt tests, deformation measurements in the fracture zones Singö and around the silo), for monitoring of groundwater pressures and groundwater chemistry and for monitoring of saturation and pressure build-up in the silo buffer. A yearly monitoring report is submitted to SKI, including results and monitoring plans for coming years. The report by /Axelsson et al, 2002/ presents the hydromonitoring

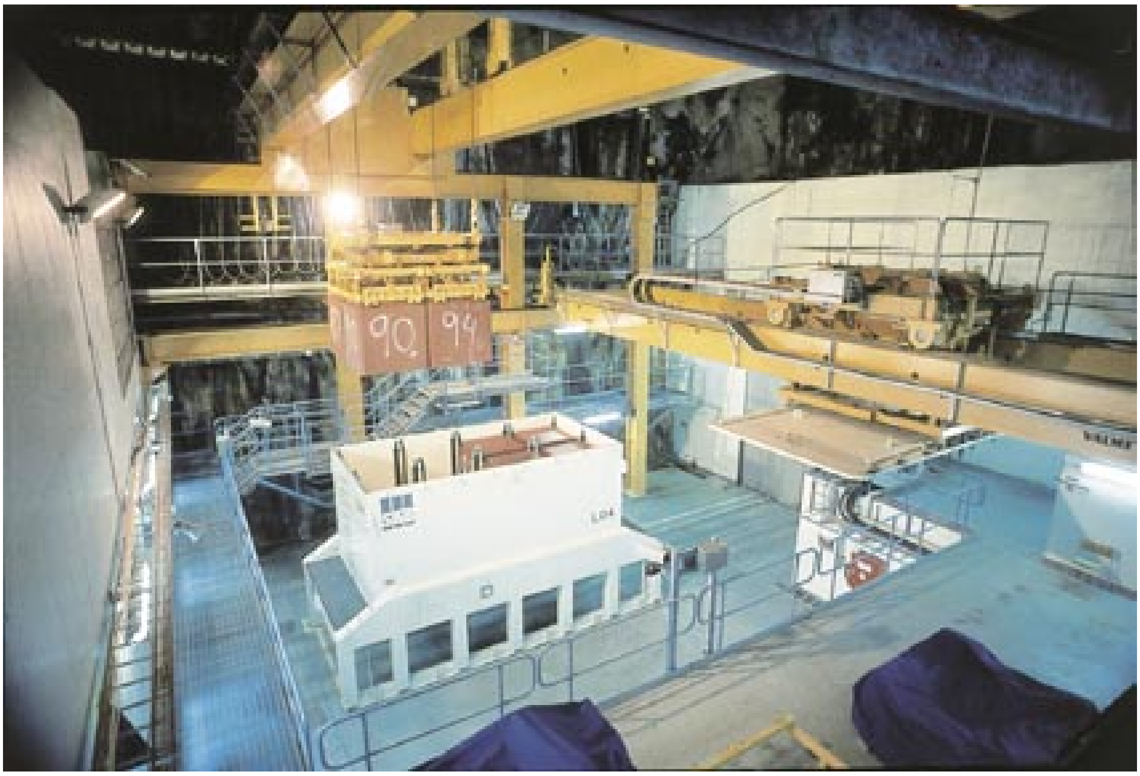

Figure 3-4. *Photo from unloading the transport container at SFR.*

programme and the revisions that took place 1995, including data from start of monitoring in year 1986 up to June 1994. The complete data set for groundwater chemistry 1989–2000 are reported in /Nilsson, 2002/.

The monitoring has proceeded well. The hydromonitoring equipment has been in operation for almost 20 years in saline conditions without major malfunctions. However extensometers for deformation measurements have been replaced several times due to the corrosive environment. One observation that may warrant further studies for the deep repository is that the bentonite saturation of the silo buffer still is insignificant and much slower than expected. Concerning the operation of the monitoring system it has been found easy to add additional data points, but in consultation with the authorities it has been difficult to remove monitoring locations that seem to be of less interest. The programme thus clearly should state the duration of measurement and conditions for removal of monitoring locations.

In addition to the aforementioned monitoring programme there is monitoring of radiation to personnel and environmental monitoring. Due to the type of waste disposed, no safeguard measures are required.

3.5.3 Monitoring at the Äspö Hard Rock Laboratory

The Äspö HRL is a "dress-rehearsal" facility to test, develop and demonstrate technology and models prior to applications at the actual deep repository, Figure 3-5. The papers presented at the 3rd Äspö International Seminar /SKB, 1998/ provides a good overview of the experience gained during the pre-construction phase 1986–1990 and the construction phase 1990–1994. During the period 1986–1994, much effort was used to characterise and

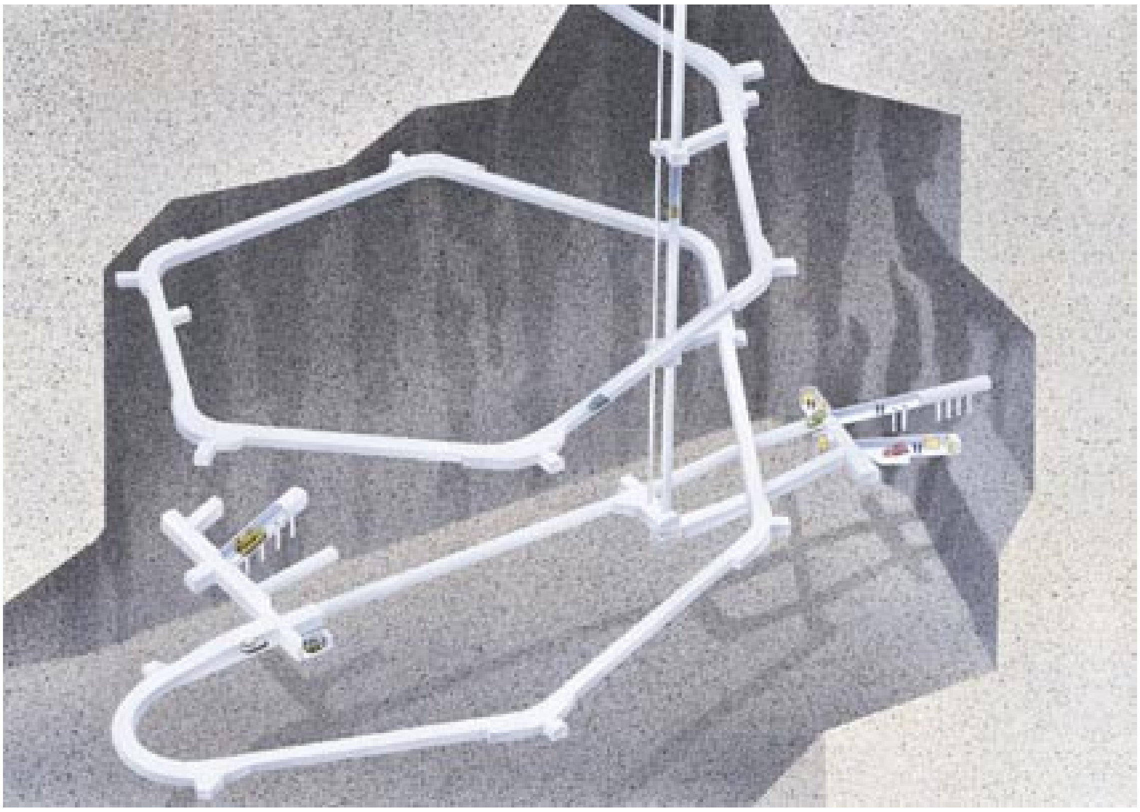

Figure 3-5. *Picture depicting the underground portions of the Äspö Hard Rock Laboratory.*

monitor all aspects of site-specific bedrock conditions. Feasibility and usefulness of field instrumentation for the pre-construction phase is described in /Almén et al, 1994/ and a similar report for the construction phase in /Almén and Stenberg, 2004/. Activities during the present operational phase are carried through to monitor barrier performance as well, in special mock-up tests like in the Äspö Prototype Repository /SKB, 2002a/, in addition to the efforts to develop site characterisation methods.

Monitoring of general bedrock conditions

Several aspects of monitoring can be mentioned, but here we limit the discussion to monitoring of groundwater. The groundwater monitoring at Äspö HRL track changes in boreholes drilled from the surface as well as from boreholes drilled from the underground openings. Parameters monitored are groundwater level or groundwater pressure and electrical conductivity of the groundwater. Äspö HRL is located on a small island with stable top-surface boundary conditions in the far-field. Observations from the tunnels provide water inflow to the tunnel. Barometric pressure, sea level changes, precipitation and temperature are recorded as well. To give an indication of the amount of measurements involved, the number of groundwater pressure points for a ten-year period has been compiled, Figure 3-6.

The groundwater monitoring system that is in place today is a result of a gradual and stepwise evolution throughout the different phases of the development of the Äspö facility. The present system named the Hydro Monitoring System (HMS) is a complete and flexible package with software and hardware to collect and process the data. To be able to use the monitoring system for hydraulic interference tests a pressure value is scanned for example once every two second. If the change since latest stored value exceeds a "change value" of a few kPa the newly scanned value is stored. A value is always stored once every second hour, unless the change.

Due to the many simultaneous activities ongoing underground it is vital to track and record all events that may influence the monitoring results. The SKB has developed in-house software SICADA (SIte ChAracterisation DAtabase) to store all data along with activity logs tracking events that may disturb groundwater pressure or flow /SKB, 2000/.

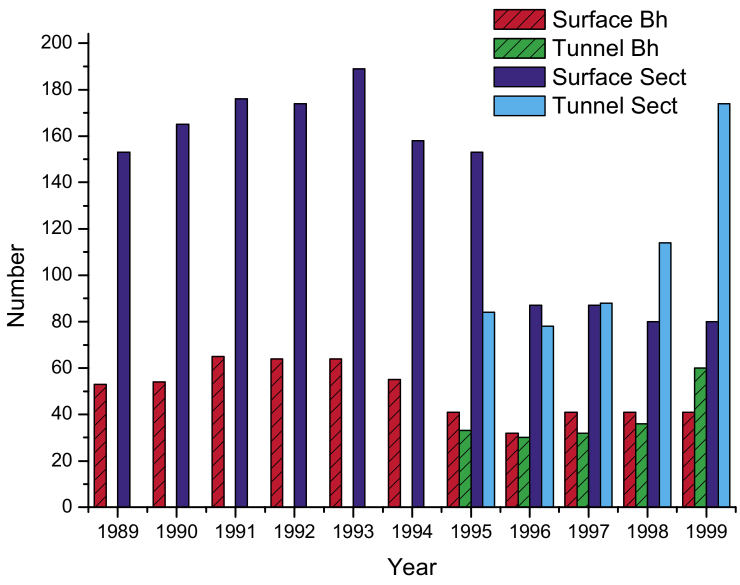

***Figure 3-6.** Number of groundwater monitoring points at Äspö HRL 1989–1999.*

The experience from groundwater monitoring Äspö HRL has been most useful to develop know-how on how to plan, install, operate and decommission a monitoring system /Nyberg et al, 2003/. With respect to operational aspects, there are issues to improve:

- Easy and fast access to sensors to facilitate corrective maintenance and subsequent reduction of groundwater disturbance and data loss.
- Technology to measure in situ chemical parameters on line to considerably strengthen the integrated hydraulic and chemical evaluation and modelling of the groundwater system.

Monitoring of barrier performance

Several barrier performance experiments have been executed or being in progress. Here we limit the discussion to the Prototype Repository.

The Prototype Repository experiment is executed to test and demonstrate the deposition sequence and to understand and qualify the processes that take place in the engineered barriers and the surrounding rock. The execution of the experiment is a dress rehearsal of the actions needed to construct a deep repository from detailed characterisation to re-saturation of deposition tunnels and backfill of tunnels. The Prototype Repository provides a demonstration of the integrated function of a repository and a full-scale reference for tests of predictive models concerning individual components and the complete system. It is conducted at 450 m depth at the Äspö HRL with six deposition holes. Heaters inside copper canisters simulate the heat from the waste. The canisters are surrounded by a clay buffer and the tunnels backfilled with a mixture of bentonite and crushed rock, Figure 3-7.

Monitoring of the Prototype Repository is of two types; one is for monitoring the boundary and initial conditions in the surrounding environment to the prototype, Figure 3-8, the second type is monitoring for the actual performance of the canister and buffer in the KBS-3 system, see an example in Figure 3-9. The following processes are monitored:

- temperature evolution in canister, buffer, backfill and rock,
- hydraulic conductivity and hydraulic head of the near-field rock,

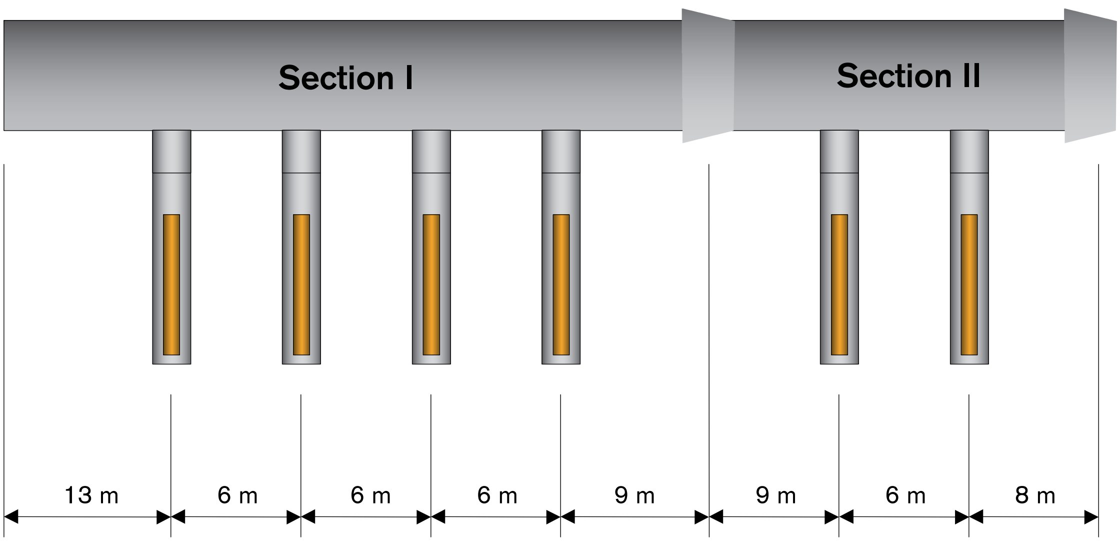

Figure 3-7. *Layout of the Prototype Repository. The diameter of the circular tunnel is 5 m and the diameter of the deposition holes 1.75 m with depth of around 8.2 m.*

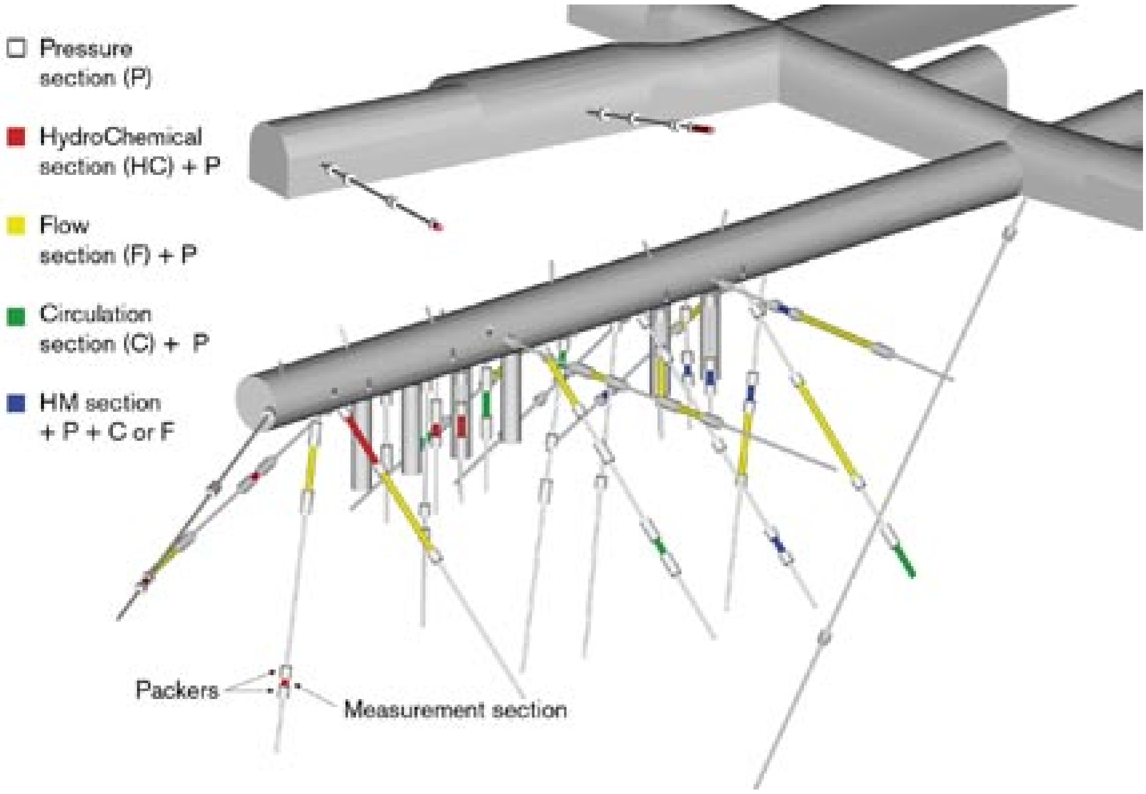

Figure 3-8. Picture from monitoring of the Prototype Repository. In total 1056 sensors (December 2003) are used.

Figure 3-9. Photo showing installation of displacement sensors on top of the mock-up canister.

- stresses and displacement in the near-field rock,
- coupled hydraulic and stress regimes,
- wetting of buffer and backfill,
- evolution of pore pressure in buffer, backfill and rock,
- evolution of swelling pressure and displacement in buffer and backfill,
- displacement of canisters,
- gas composition in the buffer and backfill and
- chemical composition of the buffer and backfill pore waters and of the water in the near-field rock.

The Prototype Repository is an example of monitoring the barrier performance for a mock-up. Figure 3-9 illustrates that monitoring of the barrier performance in the deep repository would be precarious (and then shall not be conducted) as it would be impractical to install, maintain and decommission a monitoring system, not the least in consideration of the neutron and gamma radiation from the spent fuel canisters and not to impair the post-closure performance of the barriers.

3.6 Discussion

From the presentation of studies within IAEA, OECD/NEA and EU (Chapter 3.1–3.3) it is evident that there is an international framework for monitoring in place or under development. However the national strategies for monitoring are not harmonized. As stated in the recent report from the European thematic network on monitoring (CEC, 2004) and evident from Chapter 3.4 we may anticipate three different strategies:

- Little or no monitoring is planned close to the waste.
- Small-scale monitoring will take place in a pilot facility that is developed at the repository site in parallel with the development of the repository.
- Monitoring will take place in the Engineered Barrier System relatively close to the waste itself.

SKB made in 1986 a strategic decision to develop an Underground Research Laboratory (Äspö Hard Rock Laboratory). The granitoid host rock at Äspö Hard Rock Laboratory provides a good setting for all relevant phenomenological studies in geology, rock mechanics, geohydrology, hydrogeochemistry and microbiology and how such a rock interacts with the engineered barrier systems. The laboratory is also used to test and develop technology and to prepare practical specifications for the work in the repository environment. By acquiring the appropriate understanding in the dedicated research facility, the need to monitor and confirm the barrier phenomena during the repository implementation would be limited.

A second strategic decision was to construct the deep repository in two phases: In the first phase – the initial operation phase – approximately 5–10% of the spent nuclear fuel, i.e. about 200–400 canisters will be emplaced. It is anticipated that this initial operation will provide experience on the quality of transport and emplacement methods and other operational aspects. Monitoring of the operation of the repository, including aspects of safeguard would be an integral part of the programme.

SKB has over a range of years accumulated extensive experience to monitor underground non-nuclear and nuclear facilities including:

- bedrock conditions before and during construction and operation of the facilities,
- information-based design to engineer the underground facilities based on monitoring and measurement results during construction,
- the safe and environmental construction and operation of facilities,
- monitoring of barrier function at SFR, the final repository for low – and intermediate level waste and at the Äspö Hard Rock Laboratory (mock-up) and
- monitoring for safeguard at CLAB, the interim storage for spent nuclear fuel.

The know-how relates to all aspects from design, installation, operation and maintenance to decommissioning of systems. Useful and feasible sensors and communication systems are available to monitor safety-relevant issues. Routines are available to ensure monitoring data are relevant, quality assured, traceable and transparent. The experience is invaluable to detail plans for monitoring of the deep repository.

4 Elements in SKB's monitoring programme

This Chapter presents a suggested framework for planning the monitoring programme for the deep repository. Opportunities and limitations for monitoring a KBS-3 system with focus on aspects that may have implications for operational or post-closure safety or concerning safeguard issues are discussed as well.

4.1 Rationales for monitoring

Monitoring during the stepwise implementation of the repository is executed of several reasons mainly to:

- describe the primary baseline conditions of the repository site,
- develop and demonstrate understanding of the repository site and the behaviour of engineered barriers,
- assist in the decision-making process,
- show compliance with international and national guidelines and regulations.

Specific rationales for monitoring are to:

- obtain knowledge of undisturbed conditions in nature and their seasonal variations (baseline) in order to identify and evaluate the impact of activities related to the deep repository during different phases,
- obtain a better understanding of the function of the deep repository system to support the safety account and to test models and assumptions,
- monitor the environmental impact of the deep repository,
- provide evidence that the working environment is safe with regard to radiological and non-radiological effects,
- show that requirements on radioactive waste verification (safeguards) are fulfilled.

4.2 Elements of a monitoring programme

A basic principle for monitoring is that monitoring of the site conditions and other conditions be closely tied to the general implementation programme. The monitoring programme is not viewed as an independent activity but as a well-integrated task in the site-specific programme of investigations from the surface and from the underground and in the construction, operation and closure of the repository. The monitoring programme should comply with the regulatory framework meaning that possible safety implications of installing, operating and decommissioning of monitoring systems should be evaluated in compliance with the regulations.

The monitoring programme should at least entail the following:

- objectives for the monitoring programme,
- scope for the monitoring (criteria for selection of issues to be monitored, identification of the properties, processes, phenomena and observable quantities to be monitored),
- identification on what methods to be used,
- operation of the monitoring system (identification of the duration and frequency of monitoring, including criteria for when monitoring may terminate, quality control and reporting results from monitoring, decision on trigger levels for actions, decisions on what actions should be pursued in case trigger levels are exceeded).

The general design requirements /SKB, 2002b/ are applicable for any monitoring systems introduced as well.

4.2.1 Objectives

The basic rationales in the preceding section 4.1 is a good starting point for determining detailed monitoring objectives, but it would be a part of the planning process to focus the monitoring programme and regularly check and update the objectives.

4.2.2 Scope for the monitoring

Criteria for selection of issues

The updated safety assessments for operational safety and for the long term safety are foreseen for each major phase in the repository implementation. The results of monitoring provide data on boundary conditions, initial conditions for those analyses as well as a good quality data set that can be used to calibrate the models applied for the open and the closed repository.

It is foreseen that the licences granted will require monitoring of environmental impact to check that stipulated conditions are complied with. During the construction of the underground facility information-based engineering is applied and monitoring of bedrock conditions is used to detail the layout of the repository and adapt it to the rock conditions at hand.

The non-nuclear operation of the facility requires monitoring to determine preventive and corrective maintenance and to detect adverse conditions like fires, flooding and break-down of supply systems or equipment and installations. The standard operation of the work place also requires monitoring of noise, gases and rock support and other factors to satisfy requirements for occupational safety and environmental impact. The nuclear operation requires measurements of radiation doses to personnel as well as monitoring of safeguard issues.

Issues to be monitored should be:

- of relevance to meet the general monitoring rationales,
- be shown not to compromise the operational or long term safety,
- feasible to monitor, either directly or indirectly by combining one or several parameters,
- deemed to provide useful information that is traceable and reliable.

Identification of the properties, processes, phenomena and observable quantities to be monitored

The detailing of a monitoring programme can be grouped by monitoring of the:

- man-made impacts like traffic, pollution sources, roads, wells, industrial development, population etc. This information is needed to track changes of the established baseline conditions that may influence other monitored parameters,
- surface ecosystems like forestry, agriculture, climatic variations etc,
- bedrock conditions, like geothermal conditions, groundwater conditions, rock mechanics etc,
- underground facility with its non-nuclear installations,
- repository components, like canister, buffer, backfill and bulkheads.

Identification of the properties, processes, and phenomena to be monitored for the long term safety evaluations are inherently tied to the contents of the safety assessments. The safety assessments for long term safety are based on fundamental scientific work and the features of relevance are conveniently grouped into T- (Thermal), H- (Hydro) M- (Mechanical), C- (Chemical) and B- (Biological) processes for a set of anticipated scenarios for the repository evolution. /SKB, 1999/. The report on general design requirements /SKB, 2002b/ also provides necessary, but not sufficient information to identify processes and phenomena to be monitored. The processes to be monitored should be essential for the evaluation of the performance of the repository system and chosen with care in due consideration of benefits and costs.

The basic quality to monitor would be "long term safety", but this is not possible. Neither is it possible to directly monitor the "evolution of the repository" nor "changes in groundwater chemistry" by definition of single parameter monitoring. The resort is to combine one or several process parameters into "key indicators" that captures the essential of the process or feature. Example: Temperature monitoring is a good lumped key indicator for the radioactive decay where it would not be possible to identify and track the individual element behaviour.

It is sensible to determine key indicators in the monitoring programmes as the tracking of key indicators can provide early information of how the overall system would develop. The key indicators may also be indicated in the safety assessments of operational and long term safety.

4.2.3 Identification on what methods to be used

Identification and selection of methods to be used is an optimising exercise where benefits and costs are compared. Comparative benefits are for example accuracy, reliability and durability of equipment. It is useful to include a LCC (Life Cycle Cost)-analysis accounting for design, purchase, operation, and maintenance/replacement and recycling of the system. Investigation methods for the ongoing site investigation phase are described in /SKB, 2001b/.

4.2.4 Operation of the monitoring system

Identification of the duration and frequency of monitoring, including criteria for when monitoring may terminate

Monitoring is exercised either to track changes or to prove that there are no changes. For the former case, the duration of monitoring would cover the duration of expected changes with a frequency of sampling that is sufficient to make the data useful for the monitoring objectives for that particular monitoring point. It is later a judgement to decide whether a permanent stationary situation is arrived at so monitoring can terminate.

The latter case to monitor where no changes are expected, there can be no fixed duration as to prove "no changes" monitoring will have to continue to prove a stationary condition.

If deemed necessary, redundancy can be incorporated in the monitoring system as the system cannot be developed with 100% guaranteed availability or that maintenance/replacement of sensors of other equipment is made between two consecutive samplings without unnecessarily disturbing the system.

Quality control and reporting of results of monitoring

The general SKB Quality System will be applicable and implemented for the monitoring system and the monitoring results as well as for any other data collected. Results from monitoring must meet very high demands on reliability, as they will provide the basis for decisions on further repository development, remedial actions and possibly retrieval. It is not acceptable if erratic monitoring data result in, possibly comprehensive, unnecessary actions that cause serious environmental effects or hazards to workers. It is thus a requirement that it should be possible to check and calibrate monitoring instruments and that raw data, calibrated data and evaluated data are kept separated. It should also be possible to verify that no data have been tampered with.

Monitoring results would periodically be compiled, analysed and distributed to various stakeholders (e.g. licensing authorities, operator, scientific community etc) by imaging databases, printing hard copies or by providing direct access to the database and the results.

Archiving of data and making data available for future generations can be considered as an important aspect of "long term monitoring" which from the scientific point of view could even be more relevant than actual measurements during the post-closure phase /CEC, 2004/. It is foreseen that systems for securing and archiving information will be developed and that requirements are imposed in the licences, not least the licence to close the repository and enter the post-closure phase with institutional control.

Trigger level for actions

As shown before, it is a delicate task to establish practical trigger levels for actions and such undertaking would be facilitated by a thorough understanding of the overall system. Regular updating of models for example by using a predictive modelling with uncertainty levels would provide guidance what can be decided as abnormal behaviour that may require pre-determined actions.

In case of compliance monitoring, trigger levels for actions may be set lower than the levels in the requirements so premeditated counter-measures are provided for if necessary.

Actions to be pursued in case of trigger levels exceeded

A trigger level is not necessarily an "alarm threshold" value. Typical actions for a pre-determined trigger level may be "make a study", "revise the model" or "re-design".

The use of monitoring system is used to support design and design changes are a part of information-based design /Hazelrigg, 1996/. A typical application of the information-based design is the "observational method". The idea with the observational method is the prior identification of most probable, favourable and unfavourable conditions and pre-established design alternatives accounting for the rock conditions and other conditions that are at hand /Bäckblom and Öhberg, 2002/. The truthful application of information-based design making full use of monitoring results should be in no conflict with the request of authorities to approve design work before construction, but should rather limit possibilities of delay during the construction and operation of the repository work as the pre-established action alternatives may be approved of before construction and operation is launched.

In case the trigger level is an "alarm threshold" value, information will have to be passed to the stakeholders in line with existing routines. If changes are of relevance for safety, they need to be approved of by an independent safety reviewer /SKI, 1998/ in addition to possible review and confirmation by the SKI.

4.3 Establishing the Primary Baseline conditions

The general idea with establishing the Primary Baseline conditions during the site investigations from surface is to get a reference against which the changes caused by the repository development can be recognised and distinguished from natural and other man-made temporal and spatial variations in the repository environment.

These changes observed are useful for many purposes as the observed anomalies may be compared to predicted responses to accept or decline scientific models of the site or of the repository, to adapt and refine repository design to the geological conditions at hand and to calibrate models included on the safety assessment. The confidence in the site-specific models is a keystone for decisions for how to continue the programme; the comparison of monitoring data with the Primary Baseline conditions is thus a major exercise in any implementation of a geological repository.

The second aspect of comparison besides the development of scientific and technical understanding is to clarify the short-term environmental impact by the repository implementation and also to demonstrate compliance with any requirement imposed in the construction, operating or closure licence.

The Primary Baseline established for the site should be sufficiently broad so even questions and issues not anticipated today can be resolved in the future. The work to establish the baseline conditions benefits from the scrutiny of possible small and large effects by the disposal implementation. It is helpful to understand the likely changes due to the repository implementation, the conditions that are likely to be affected, the potential consequences of the changes as well as understanding of how other changes not made by the repository project could change the baseline. It is also useful to establish beforehand how changes to the baseline conditions will be interpreted.

It is also imperative that baseline conditions are properly established and fully documented with high quality so the conditions are understandable and transparent even several decades after data collection. Monitoring of baseline conditions is needed over a sufficiently long period of time so that the seasonal, annual and longer-term variability of ongoing natural processes can be evaluated, for example changes to groundwater flow rates and directions. Clearly the time interval over which this monitoring should be performed must relate to the period of the natural variations at the site to ensure that likely maximum and minimum parameter values of relevance to repository behaviour are experienced and measured. Where important parameters show a cyclic, increasing, or decreasing behaviour, monitoring of the baseline conditions needs to be continued until this trend is established with sufficient confidence. In the evaluation of baseline conditions, perturbations caused by investigations activities (drilling, sampling) should also be well understood.

In order to assess the effects of all phenomena occurring during construction, operation and closure of the final repository it is important to have a good understanding of the natural system prior to it being disturbed. Thus, monitoring activities in the pre-operational stage begins at the earliest possible time, but, in any case, before the perturbations caused by repository construction and operation begin to accumulate.

The rationales for the Primary Baseline conditions established are conveniently grouped in four different categories:

- **Engineering:** Conditions deemed necessary to support the engineering of the repository. Systematic use of information-based design is favoured so that engineering plans and other plans take accounts of the results from the baseline conditions and tailor the design to the conditions at hand.
- **Safety case:** Conditions that are used to prepare the safety case. The baseline conditions established should by and by confirm the understanding of the geological, physical, chemical and biological processes present on the site and to support decisions on the suitability of the engineering and showing that the site is not compromised during the implementation.
- **Environmental impact:** Conditions that are monitored to track environmental impacts and to show compliance with stipulated environmental requirements. The impacts are typically consequences of drawdown and diversion of groundwater due to repository construction, airborne releases, noise levels, visual amenity etc.
- **External, local effects on baseline conditions**: Situations that have effect on the baseline conditions (“boundary conditions”) and so have an effect on the interpretation of the results of the change. This could include aspects such as new roads, new industries that may change the infiltration of surface water into the bedrock

4.4 Understanding of the repository site and the behaviour of the engineered barriers

Understanding of the repository site and the behaviour of the engineered barriers is based on several types of information, like general progress of science and technology, technology and methods available to study the mechanical, physical, chemical and biological process and the availability of site-specific data. The discussion here is mainly dealing with the opportunities and limitations for monitoring. The construction of the repository is made in steps and an overview of the possible implementation phases are presented in the subsequent sections. The overview is tentative and will develop with time.

4.4.1 Construction and detailed investigation phase

Following the site investigation phase, construction is initiated and co-ordinated with bedrock investigations from underground and from the surface. After around 6 years of construction most of the facility has been prepared for the initial operation phase, see Figure 4-1.

From a general standpoint it is likely that the underground characterisation programme will be similar to the programme adopted for the construction of the Äspö Hard Laboratory, see the papers in /SKB, 1998/. The parameters to be explored will most likely be almost the same as those explored during the site investigation phase, see Chapter 5 but with improved possibilities of obtaining a detailed account of the rock close to the tunnels and the possibility to study the impact of the underground construction on these properties. From the SKB perspective the monitoring during the construction phase will focus on developing an extended understanding of processes affecting repository safety (geohydrology, groundwater chemistry, rock mechanics), but also to follow the continued disturbance on the rock created by the excavation itself as well to show compliance with any environmental regulation. The monitoring will possibly continue in a selection of the boreholes drilled from the surface, but additional monitoring will take place in the tunnels and from a selection of the investigation boreholes drilled from the tunnel.

In addition to bedrock monitoring the facility will be monitored for fires, occupational safety etc like in any underground facility.

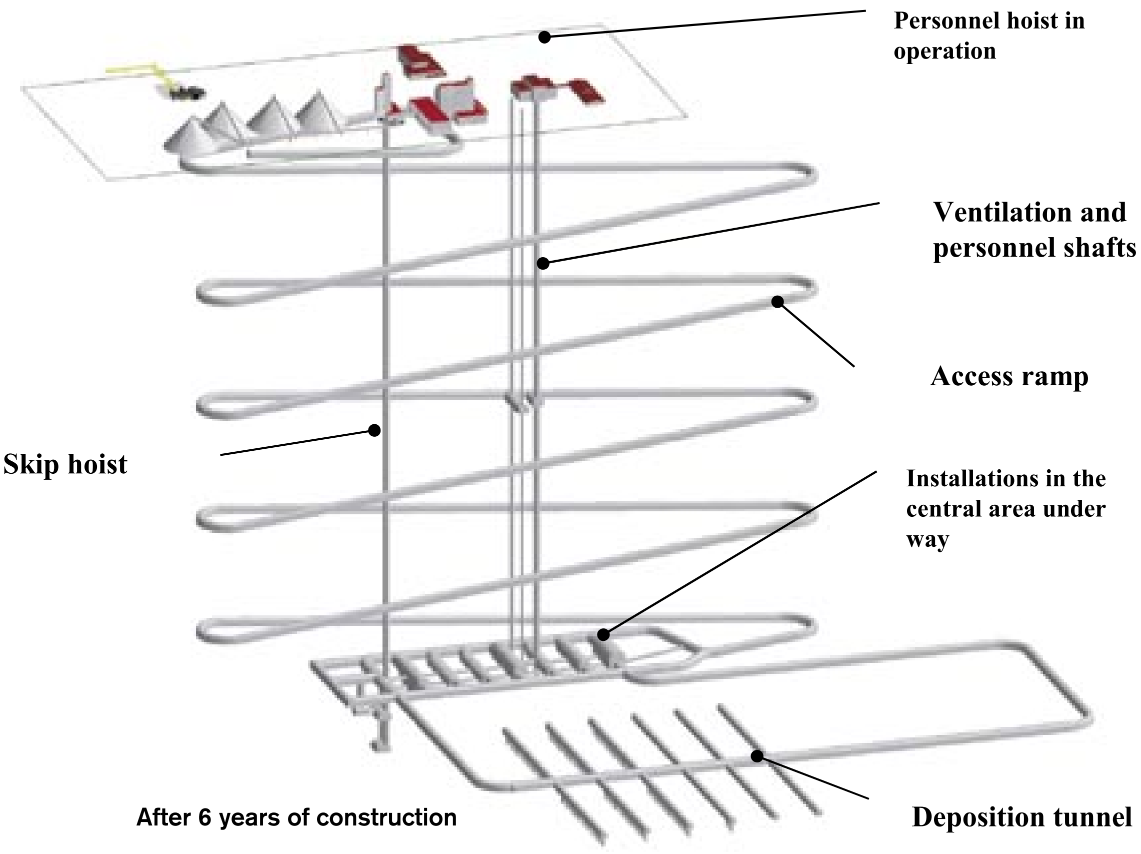

Figure 4-1. Sketch of the deep repository after 6 years of construction.

4.4.2 Initial operation phase

The initial operation phase is the period starting when spent fuel canisters are deposited underground, see Figure 4-2. Deposition work and backfilling (Figure 4-3), drilling of deposition hole and excavation of the main tunnels for the area for regular operation are concurrent activities with the extended bedrock investigations from underground and from the surface. After a deposition tunnel is backfilled completely, a bulkhead is constructed to limit axial groundwater flow in the deposition tunnel and to provide a counter-pressure to the swelling pressure of the bentonite/rock backfill mixture

The transport of canisters from the encapsulation plant and start of deposition of the spent fuel makes the repository to a "real nuclear facility" and several regulations concerning nuclear safety and safeguard are in force like for any nuclear facility. Detailed requirements concerning the operation and monitoring may also be stipulated in the permit to operate the facility.

Monitoring of the emission levels of radioactivity or other substances in the environment, similar to the presently existing general environmental control of drinking water, can be done without affecting the repository system. The correlation between a registered signal and the repository performance is, however, weak. Given the robust isolating properties of the disposal system it can certainly be argued that it is not justified to monitor radionuclide content in or around the repository. No radionuclides will be released, nothing will be registered and the measurements will have no value as evidence for a safe repository. Should equipment for post-closure monitoring be introduced in the repository, their consequence on the safety must be evaluated, including an analysis of the possibility for equipment failure and false signals and the consequences of possible actions.

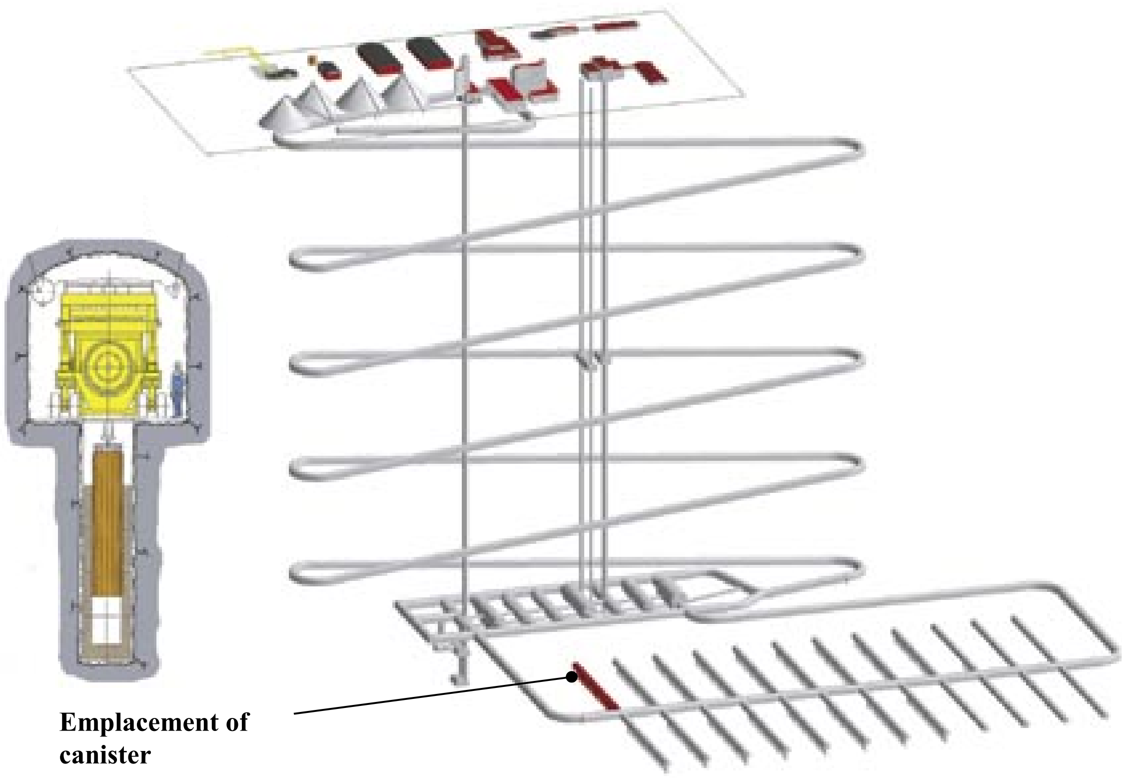

Figure 4-2. Deposition of canisters during the Initial Operation Phase.

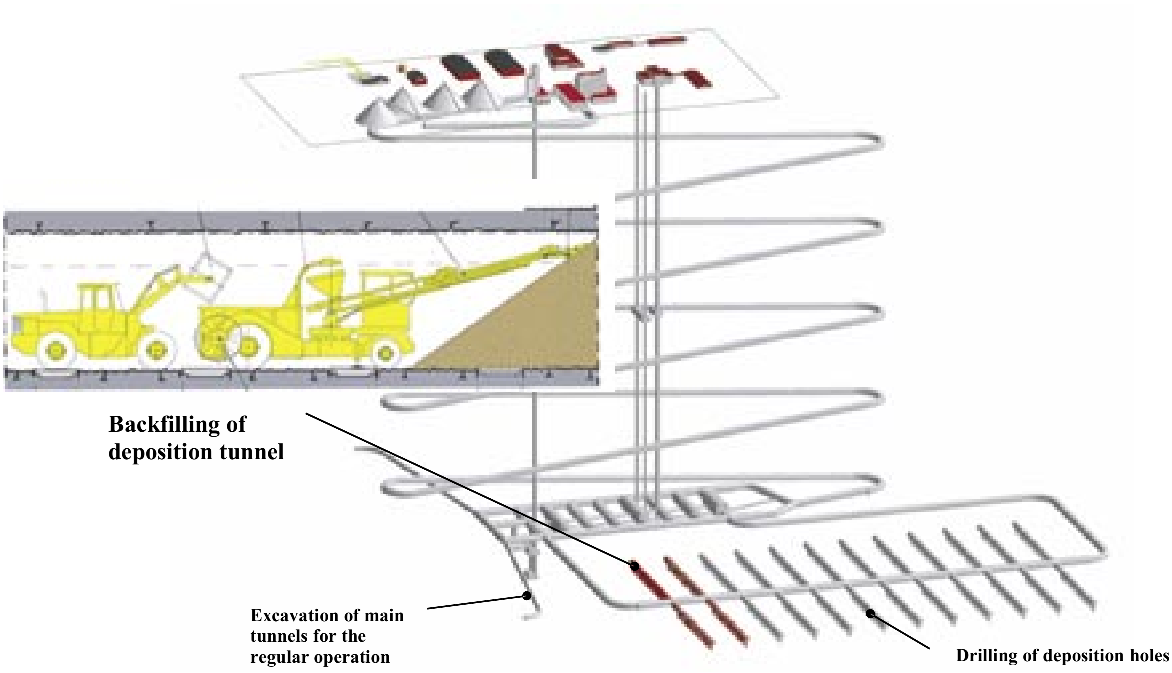

Figure 4-3. Backfilling of deposition tunnels follows immediately after deposition of the canisters.

After deposition and backfilling of deposition tunnels monitoring of parameters (like temperature, micro-seismic events, hydraulic regime, re-saturation or pressure build-up in the backfill) may commence to evidence that important processes are developing as expected and as assumed or predicted in the safety assessment.

Processes in the buffer and the surrounding rock are measured and studied in several of the experiments in the Äspö HRL, which provide a good enough understanding during the conditions prevailing in the underground laboratory. There will be small differences between the experiments and conditions in the actual repository, mainly related to radiation from the canisters and possibly different ground water composition. The consequences of these differences are thoroughly studied in surface laboratories, but can probably not be measured in the actual repository without having instruments in the buffer. Such instruments cannot be accepted, as they would jeopardise the integrity of the buffer or the near-field rock and also increase the operational risks to the personnel.

Monitoring during repository operation would likely shed more light on the transient processes rather than the conditions that will prevail in the closed repository, when groundwater pressure is completely restored and all free oxygen is consumed in the repository and a large-scale rock mass is moderately heated. However, one possible way to collect information of potential use, if deemed necessary, would be to set up a few instrumented deposition holes, which later are decommissioned, the canisters retrieved from the hole and deposited in new and final positions. Basically such monitoring of the instrumented deposition holes could go on for decades but be decommissioned well in advance before submitting the application to finally close the repository. The rationales would be to verify that the initial conditions used in the analyses of long term safety are reasonable and to show that the disposal area evolves in agreement with the expected transient behaviour of the system.

It is planned that deposition and construction are concurrent activities. In the case excavation work is by drill & blast operation, it would be required to ascertain that neither the deposited engineered barrier system nor vital installations not vital monitoring equipment is impaired by the blasting. Experience from the operation of Äspö HRL shows that blasting operation occasionally causes permanent changes to the groundwater levels measured in the boreholes.

4.4.3 Regular operation

The regular operation will continue until all spent fuel produced has been emplaced. As earlier bedrock investigations and construction are concurrent activities with the deposition/backfilling work and it is foreseen that the monitoring programme is tailored to the needs and based on the substantial experience from previous repository phases Figure 4-4.

4.4.4 Closure of the repository

Closure of the repository is basically a step-wise procedure and it is possible to distinguish several sub-phases.

As part of the deposition work we first close a full deposition tunnel with a bulkhead to limit axial groundwater flow and to provide a counter-pressure to the swelling pressure of the bentonite/rock backfill mixture. As long as the main tunnel connecting to the deposition tunnels is open, it would be possible to conduct limited measurements of processes in the backfill and the backfill/bulkhead interface. The backfill is by SKB definition not part of the barrier system and it would then be possible to monitor the development of saturation in backfill and the contact pressure backfill/bulkhead and possible deformations of the bulkhead to ensure the appropriateness of the design of the bulkhead. When a deposition area has been filled it would be possible to backfill the main tunnels and effectively seal-off the area to restore the reducing conditions of the groundwater as soon as possible. The behaviour of the sealed-off area may be monitored by seismic methods to track possible rock movements and temperature as well.

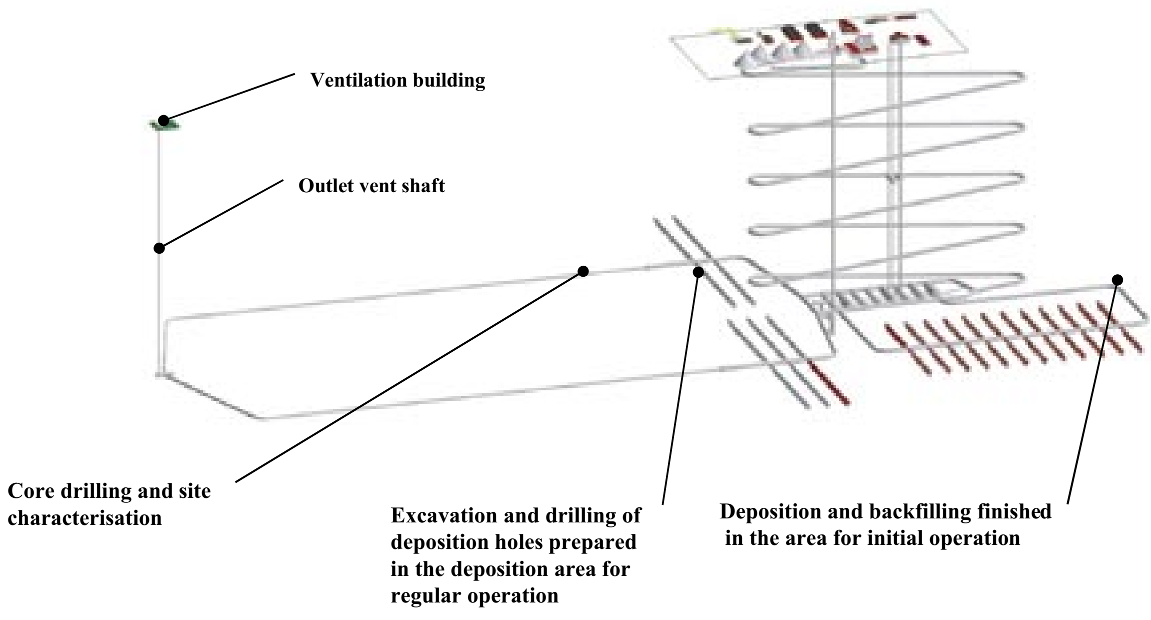

***Figure 4-4.** Continued bedrock investigations, construction and deposition activities during the Regular Operation Phase.*

When the deposition of spent fuel is completed the closure of the repository may start with backfilling main tunnels, central area, ramp and shafts. It would not be practical to monitor the development of temperature, re-saturation etc from the underground as the sensors and network would not be possible to operate. It is however anticipated that the surrounding surface boreholes may be used to monitor the general temperature, restoration of natural groundwater conditions as well as tracking of micro-seismic events that may take place. Post-closure monitoring of the deposition tunnel might include chemistry of water leaking from the bulkhead as well as development of the pressure to the bulkhead and its deformations. The first deposition area is the area used for spent fuel deposited during the initial operation.

It is important to realise that post-closure monitoring may not only be for the whole of the repository, but as well for parts of the repository previously closed while other parts are open and running, c.f. the licence for the WIPP-facility, Section 3.4.6

A guideline in the planning of instrumentation must be to have a possibility to calibrate and exchange instruments that are not working well. This means that installations made underground cannot continue in operation after the closure of the repository, only surface based installations.

4.4.5 Post-closure of the repository

As mentioned before, a basic requirement is that the long term safety of the geological repository is not dependent on monitoring, maintenance or institutional control after closure. However, it is possible some institutional control would be exercised after post-closure to verify safeguard requirement A method could be remote sensing by micro-seismic networks /ESG, 2002/. The restoration of the surface ecosystem may also be monitored for a limited period of time and compared with the Primary Baseline conditions established prior to the construction of the repository.

The extent of the post-closure monitoring programme will essentially be given by the decisions made at closure. It is appropriate that any decisions on post-closure monitoring are taken by the generation that is the decision-maker at the time of closure. While the responsibility for the repository is transferred to the State after closure it is then also needed to clarify the responsibility for execution of the post-closure monitoring.

4.5 Decision-making process

The implementation of the geological repository is a stepwise process where stakeholders are either required or encouraged to provide input to the decision-process.

The types of decisions are on several levels and may be political, legal, technical or administrative. Major permits are required for approval of the site, start of construction of the repository and also for closing the repository when also the responsibility for the repository is transferred from the industry to the State. It is natural that the monitoring results from the ongoing work are a useful subset of all necessary data to analyse operational and long term safety, to ensure compliance with environmental and other requirements as well as to optimise the design of the repository.

While the monitoring programme will entail the building blocks described in Chapter 4.2, it is anticipated that the monitoring results are consistently reviewed by the implementer and the pertinent authorities that also will comment or rule on the decisions to be taken based on the monitoring results. The smooth decision-process requires a clear responsibility and subsequent authorisation of the decision-making. Monitoring results may result in decisions on new types of measurements in new locations, change of working procedures for site characterisation or construction activities that improves the overall safety, lower environmental impact and save of time and money.

It is foreseen that the SKB internal decision-process and procedures for change management will be a part of the general Quality System.

4.6 Compliance with international and national guidelines and regulations

International guidelines for monitoring are emerging as a consequence that the programmes for geological repositories successfully move from desk studies to implementation of real facilities. The guidelines, as evident from Chapter 3.1 are not very precise, they rather suggest that a monitoring programme *shall be defined and carried out and* also suggest the purposes of monitoring.

Swedish national guidelines and regulations concerning the geological repository are discussed in Chapter 1 where it is stated that the safety impact of monitoring measures are to be analysed and reported and it is advised that the safety report *"should show that these measures either have a minor or negligible impact on repository safety, or that the measures result in an improvement of safety, compared with the situation that would arise if the measures were not adopted"*. The first occasion when the regulations concerning the deep repository /SKI, 2002/ formally can be enforced is when the application for siting and construction of the deep repository has been submitted.

SKB will for each consecutive implementation phase describe plans for monitoring and it is foreseen that the permits at major decision points may stipulate conditions for monitoring to enhance safety and maintain low environmental impact. Such "control programmes" were for example prepared in consultation with the pertinent authorities when the CLAB-2 facility was constructed (see Chapter 3.5.1).

4.7 Summary overview of typical monitoring activities for different repository phases

Table 4-1 shows a summary overview of typical monitoring activities that may take place for different repository phases.

Table 4-1. Possible monitoring activities for different repository phases.

Site investigation phase	Construction and detailed characterization phase	Initial operation, regular operation, closure phases	Post-closure phase during institutional control
Environmental monitoring programme - disturbance of surface investigations	**Environmental monitoring programme** - disturbance of supplementary surface investigations - impact of repository construction (soil, groundwater, gas, noise)	**Environmental monitoring programme** - disturbance of supplementary surface investigations - impact of repository construction (soil, groundwater, gas, noise)	**Environmental monitoring programme** - impact of rise of groundwater level **Documentation is preserved**
Climate - temperature, atmospheric pressure, precipitation, evaporation, runoff, sea level changes	**Climate** - temperature, atmospheric pressure, precipitation, evaporation, runoff, sea level changes	**Climate** - temperature, atmospheric pressure, precipitation, evaporation, runoff, sea level changes	**Climate** - temperature, atmospheric pressure, precipitation, evaporation, runoff, sea level changes
Biosphere - flora, fauna, soil layer land use etc	**Biosphere** - flora, fauna, soil layer land use etc	**Biosphere** - flora, fauna, soil layer land use etc	**Biosphere** - flora, fauna, soil layer land use etc **Documentation is preserved**
Boreholes from the ground surface - groundwater chemistry and pressure, temperature	**Boreholes from the ground surface** - groundwater chemistry and pressure, temperature	**Boreholes from the ground surface** - groundwater chemistry and pressure, temperature	**Documentation is preserved**
	Boreholes from underground - groundwater chemistry and pressure, temperature - deformations in the rock	**Boreholes from underground** - groundwater chemistry and pressure, temperature - deformations in the rock	**Documentation is preserved**
Seismic events - time, location and type of local earthquakes	**Seismic events** - time, location and type of local earthquakes - micro-seismic events	**Seismic events** - time, location and type of local earthquakes - micro-seismic events	**Seismic events** - time, location and type of local earthquakes - micro-seismic events **Documentation is preserved**
	Surveillance of the repository - fire, - floods, seeping water, pumped-out water (quantity, quality) - ventilation (temperature, quantity, quality) - noise - monitoring of conditions for preventive maintenance - stability of underground openings	**Surveillance of the repository** - fire, - floods, seeping water, pumped-out water (quantity, quality) - ventilation (temperature, quantity, quality) - noise - monitoring of conditions for preventive maintenance - stability of underground openings - radiation monitoring - safeguards	**Surveillance of the repository** - safeguards **Documentation is preserved**

5 Application of monitoring within the ongoing Swedish site investigations

SKB in year 2002 started site investigations at two sites in Sweden, Figure 5-1. The objectives of the investigations are to show whether the sites satisfies fundamental safety and civil engineering requirements, to compare the sites with other investigated sites and to adapt the repository to the properties and characteristics of the sites in due consideration of impacts on society and the environment /SKB, 2001b/. A task for the site investigations is to establish the baseline conditions in general. Preparations are under way to monitor the natural variations and to get the reference against which the future changes caused by the repository development can be recognised and distinguished from natural and other man-made temporal and spatial variations. The monitoring to establish the baseline conditions are integrated in the site characterisation programme. Figure 5-2 shows the candidate area Forsmark in Östhammar and Figure 5-3 the candidate areas Laxemar and Simpevarp in Oskarshamn.

This chapter extracts examples of the ongoing and planned monitoring during the site investigation phase, supplemented by detailed information in the Annexes. The proposed elements of a monitoring programme (Chapter 4.2) are used as a structure for the presentation and discussion of the monitoring activities.

Figure 5-1. Location of site investigations at Simpevarp and Laxemar in Oskarshamn and Forsmark at Östhammar.

Figure 5-2. Overview of the Forsmark candidate area and location of boreholes (situation autumn 2003).

Figure 5-3. Overview of the candidate areas at Laxemar and Simpevarp.

5.1 Objectives

The monitoring activities are well integrated in the general site investigation programme intended to compile the necessary data for the site-adapted layout of the deep repository, to assess the long term radiological safety, to achieve fundamental geoscientific understanding, and to identify objects that may require special environmental considerations during construction and operation of the deep repository.

Of special importance during the site investigations are to describe the Primary Baseline conditions of the repository and to obtain knowledge of undisturbed conditions in nature and their seasonal variations. The Primary Baseline is structured with respective to a set of different disciplines and their specific objectives are explained in Chapter 5.3. The baseline conditions of the investigated sites will be presented in Site Descriptions for each site containing both the primary data base and a Site Descriptive Model. The Site Descriptive Models are updated at regular intervals utilising the database that is increasing during the course of the site investigations.

5.2 Criteria for selection of issues

The issues selected for characterisation and monitoring follow from the general and discipline-specific objectives presented in the general investigation programme /SKB, 2001b/.

The possible detrimental effects on long term safety by drilling investigation boreholes from the surface *("Issues selected for monitoring should be shown not to compromise the operational or long term safety",* c.f. Chapter 4.2.2) have not been dealt with explicitly, but it is understood that these boreholes later can be sealed in order not to compromise the long term safety of the repository. It is expected that these conditions generated by boreholes be scrutinised in the safety assessment to be submitted to SKI to license the site for the repository.

5.3 Identification of the properties, processes, phenomena to be monitored and selection of the observable quantities or qualities to be monitored

Based on the objectives and needs of the repository programme properties, processes and phenomena to be monitored have been identified. The next sections outline features/process and the parameters selected for monitoring during the site investigations. The selected examples are part of the work aimed at establishing the Primary Baseline conditions before construction starts.

Each later step in the investigations may identify new data types and additional data points to be included in the monitoring programme and the information contained here will certainly be modified to adapt the monitoring programme to the needs.

5.3.1 Man-made impact

Following the discussion in Chapter 2 the Primary Baseline for monitoring are mainly concerned with "boundary conditions" and "initial conditions", but in a broader sense than the stringent mathematical context. Besides the surface and underground installations related to the disposal facility it is also necessary to track other changes in the infrastructure etc that may disturb the ambient baseline conditions; changes in communities and landowners use of land are other important data as well.

The Table A-1 is a possible list of processes, features and parameters needed to facilitate interpretation of what are natural and what are man-made impacts on the pre-established baseline conditions. The monitoring of man-made impact is necessary at all phases during the repository implementation. Examples of tracking include traffic, industry, pollution sources, infrastructure etc.

5.3.2 Surface ecosystems

The collection of data of the surface ecosystem is extensive as data are used as input in safety and performance analyses, and also to detect the environmental impact of the repository development. The Table A-2 is a comprehensive list of processes, features and parameters possible to collect to characterise the undisturbed ecosystem conditions in the candidate areas, collect relevant data for safety assessment and design, obtain a general understanding of the candidate area's surface ecosystems so as to be able to develop and justify models and make predictions of the area's future evolution and with the aid of collected data, present a framework for the further execution of the investigations with consideration for nature and the environment.

Examples of processes/features tracked are forestry, agriculture, fishing/hunting, flora/fauna, climatic variations etc. Some parameters will be followed up on an annual or an even more frequent basis such as chemical and biological characterisation of surface water, inventories of hydrogeology and hydrogeochemistry sections, flora and fauna. Surface water sampling points for the Oskarshamn area (December 2003) are shown in Figure 5-4.

5.3.3 Geology

The geology is the basis for understanding tectonic processes, rock mechanics, groundwater flow, groundwater chemistry and transport of solutes. Any site investigation programme is extensive in its nature with the ambition to describe the lithological and structural heterogeneity of the rock. The data collection is iterative and coupled to subsequent model updating. However, with a few exceptions, collection of these data is not for the purpose of baseline monitoring and is thus not included in the monitoring programme. What is of interest to monitor is data related to heat flow and temperature distribution, as the disposal of spent fuel or high-level waste will affect the local temperature field. In addition it is of value to monitor tectonic processes in a suite of geometrical scales, Table A-3. It is necessary, but not sufficient to monitor the local site conditions, as the processes are driven by global and regional processes. Only very minor seismic events (at most in the region of Magnitude 3 to 4) are expected in the candidate areas, or in Sweden as a whole. Nevertheless, there is a need to be able to explain the few events that may be encountered during the long time of the SKB presence at the sites. Furthermore, the events by themselves may carry additional information of the rock mechanical state (e.g. major stress directions). Seismic monitoring requires a seismic observational network covering a large area, as the observation of a (minor) seismic event has to be related to seismic events in a

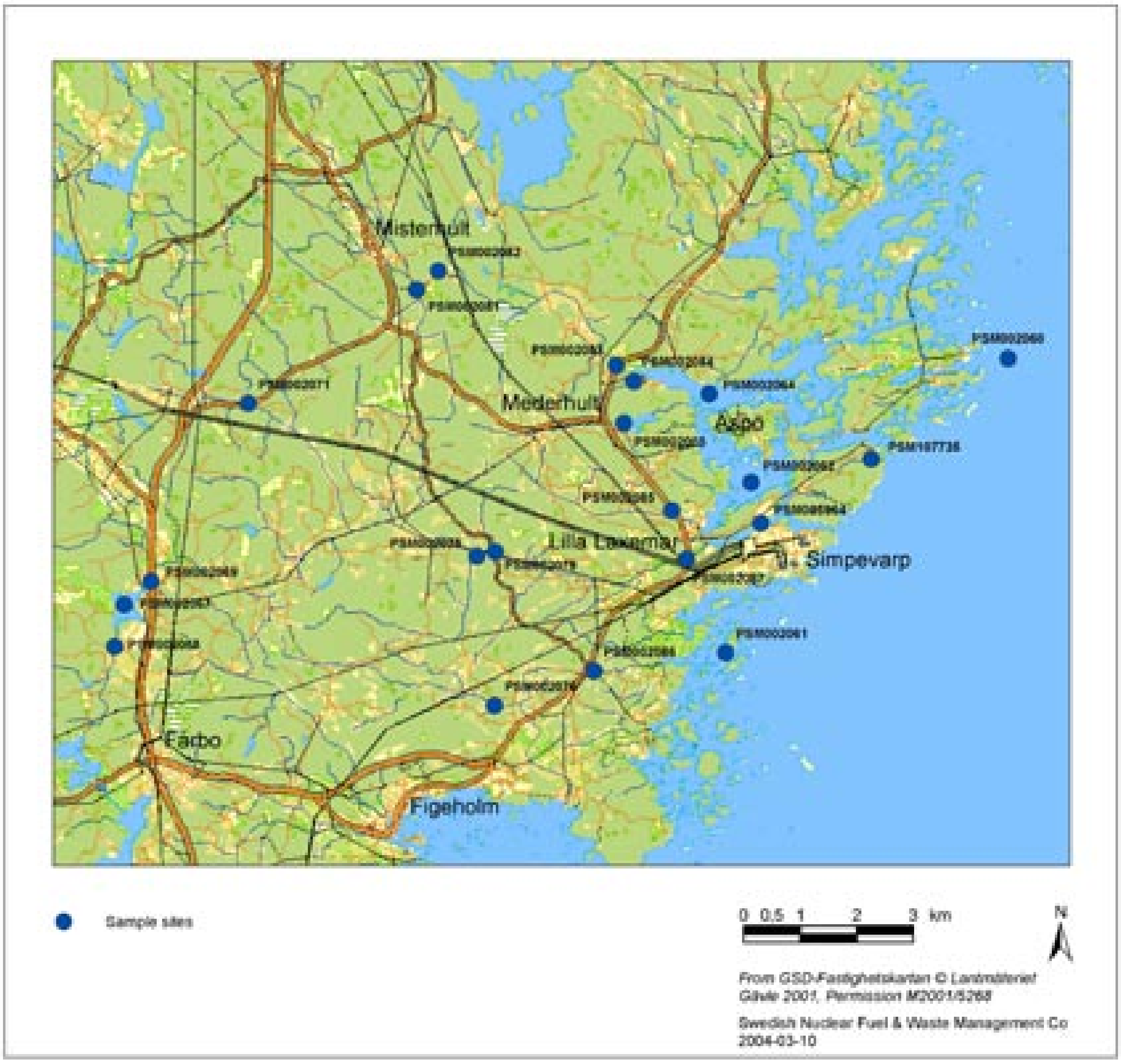

Figure 5-4. *Surface water sampling points for the hydrochemical and the ecological programmes of the Oskarshamn site investigation.*

larger region. The seismic surveillance network has been extended to cover the entire east coast of Sweden. The density of detection station established is sufficient for a detection level of about magnitude M 0.5, see Figure 5-5.

5.3.4 Rock Mechanics

Evaluation of rock mechanical processes and parameters is an important issue to ascertain occupational safety during operation of the repository, but also to ensure the good integrated interaction between the rock and the buffer and rock and backfill in the post-closure phase. The discipline-specific goals are to determine whether the selected site is large enough to accommodate a repository, determine and assess the distribution of initial rock stresses within the site, identify the risk of extensive spalling problems or other rock breakout in deposition tunnels and deposition holes, determine mechanical properties of fracture zones and individual fractures, determine mechanical properties of intact rock and various rock masses, identify possible problems where tunnels may pass fracture zones.

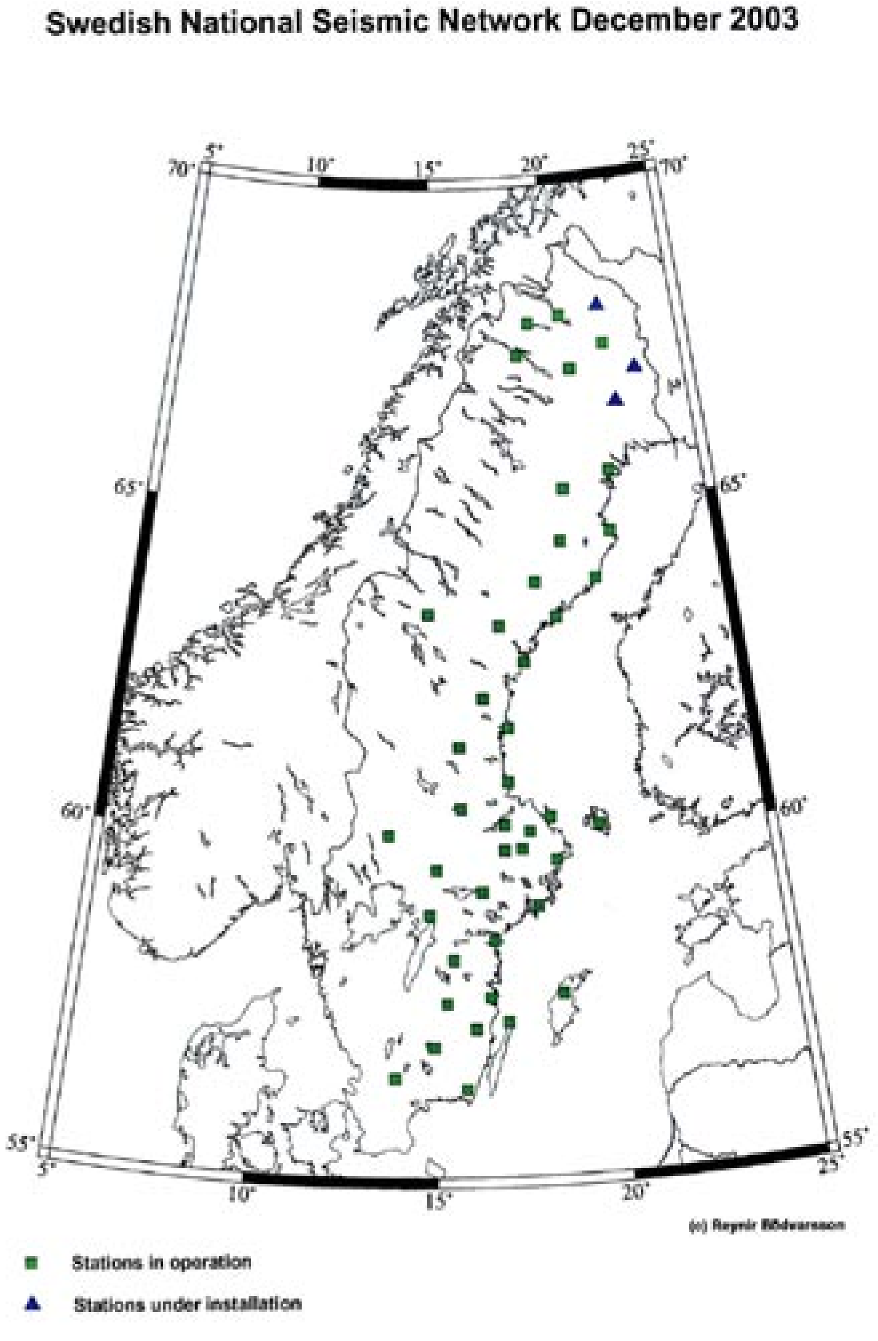

Figure 5-5. *The Swedish national seismic network /Böðvarsson, 2004/.*

The primary stress field are essentially decided during the site investigation phase but more detailed investigations will be pursued underground; these measurements are not part of the monitoring programme (c.f. the SKB definition on monitoring). The parameters suggested in Table A-4 (stresses, dynamic propagation velocity) are then not a part of the baseline conditions for monitoring purposes, but included here for sake of completeness. Interpretation of stress measurements results should preferably be well-integrated with interpretation of groundwater head measurements and evaluations of fault plane solutions from the micro-seismic network.

5.3.5 Hydrogeology

The goals of the hydrogeological programme are in brief to compile a hydrogeological description on a regional and local scale that is sufficiently detailed for judging the suitability of the site with respect to preferences regarding hydrogeological functions and otherwise meet the needs of safety assessment and design and to achieve a hydrogeological understanding on the regional scale that is sufficient to delimit and define properties and boundary conditions for regional groundwater flow models and achieve a hydrogeological understanding on the local scale that justifies the local hydrogeological description.

The precise monitoring of undisturbed absolute hydraulic pressures is a major issue in the site investigation and the monitoring programme. The data are essential to establish boundary conditions and initial conditions for subsequent modelling. Monitoring of the pressure changes (and salinity changes) during construction of the repository is a key factor for updating and refining the hydrogeological model. Monitoring is as well used to collect pressure responses during drilling, single-hole pumping tests and interference tests. The usefulness of the Primary Baseline established for hydrogeology, Table A-5 is further enhanced if the data collected are co-interpreted with the groundwater chemistry data in the host rock as e.g. the salinity concentration in the groundwater is a useful parameter for calibration of groundwater flow models. It is also imperative to gain a thorough understanding of the surface hydrology and the interface between the soil and the rock as the properties for the interface very much determine the drawdown due to the repository construction. Issues concerned with the surface hydrology are included in the tables for the surface ecosystem, Table A-2. A short description follows:

Monitoring of surface water during the site investigation includes recording of stream discharge at strategic stations and water levels in lakes and the sea, of which some have already been established, see example from Forsmark (Figure 5-6) as well as monitoring of meteorological data. Monitoring of groundwater levels is in open boreholes or in multi-packer isolated sections including standpipes in soil, percussion drilled and core drilled holes. Monitoring of the cored holes is the most comprehensive task. Monitoring of boreholes start after the single hole investigations are completed. The first installation for a cored borehole in Oskarshamn was made in February 2004. Eight sections are isolated for monitoring of groundwater level in stand pipes. Two of the sections are equipped with a circulation system enabling repeated groundwater sampling and groundwater flow measurements by means of the dilution method, see Figure 5-7. Most of the meteorological, surface water and groundwater monitoring data are collected on-line to a Hydro Monitoring System, similar to the one used at the Äspö Hard Rock Laboratory /Almén and Stenberg, 2004/.

Table 5-1 shows the sections installed in borehole KLX02 in Oskarshamn where monitoring started in March 2004.

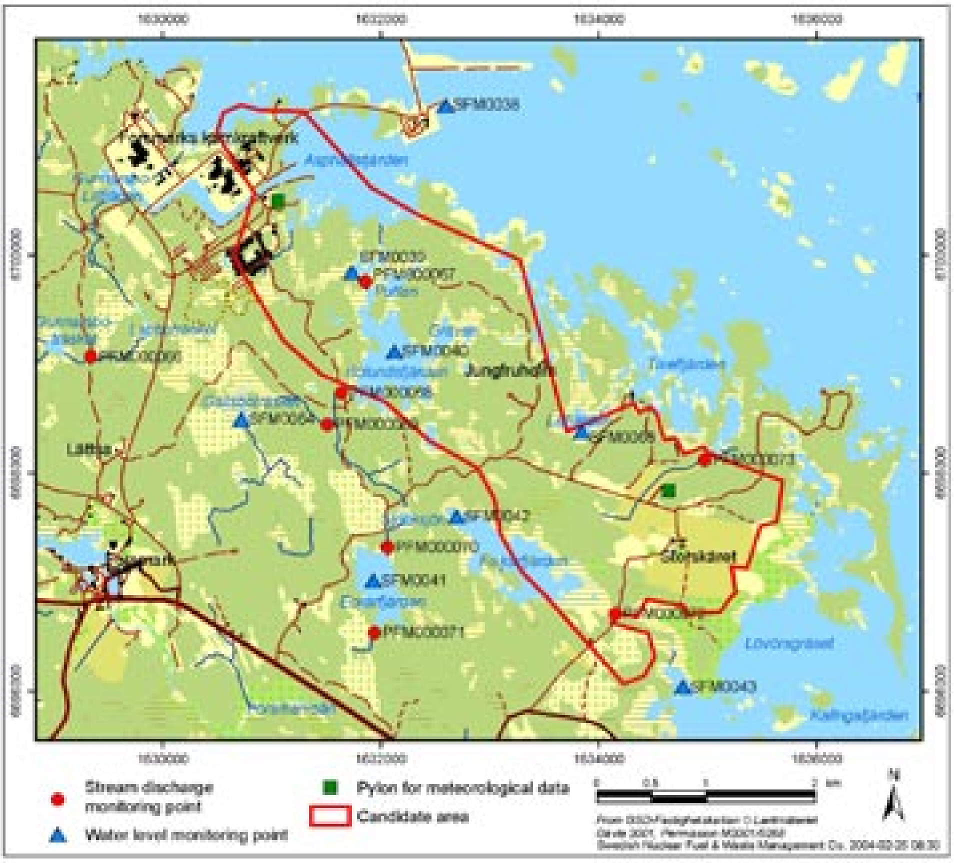

Figure 5-6. Measuring stations for surface water discharge, water level and meteorological parameters of the Forsmark site investigation.

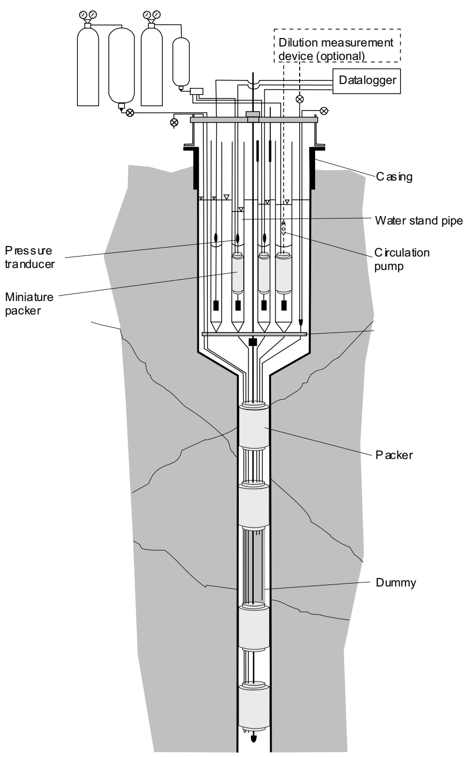

Figure 5-7. Typical borehole installation for groundwater monitoring of cored boreholes with maximum nine monitored borehole sections.

Table 5-1. Installed sections for monitoring in borehole KLX02 in the Oskarshamn (Laxemar) area.

Section	Type of monitoring
0–207 m	Groundwater level
208–347 m	Groundwater level
348–451 m	Groundwater level
452–494 m	Groundwater level, water sampling and flow measurements by the dilution method
495–717 m	Groundwater level
718–1144 m	Groundwater level
1145–1164 m	Groundwater level, water sampling and flow measurements by the dilution method
1165–1700 m	Groundwater level

5.3.6 Hydrogeochemistry

The site investigation observations are used to characterise the undisturbed hydrogeological conditions on the site and to describe the origin and flux of the water in the rock, to obtain specific data on parameters that are of importance for the safety assessment and design, such as pH, Eh (redox potential), sulphides, chlorides and amount and types of colloids, bacteria etc and to identify possible occurrence of free dissolved oxygen in the groundwater at repository level.

It is a matter of choice if the composition of the groundwater is a “material property” or “initial conditions”. For sake of consistency they are treated here as “initial values”. The initial values established are the results of mixing and groundwater/chemical/biological interactions over millions of years. Of importance in the Nordic countries is to understand the influences of previous glaciations and deglaciations and associated current land uplift. The programme for water analyses is very much aimed at finding the “end-members” of the waters – i.e. the “original waters” as a sort of “boundary conditions” to describe the subsequent mixing of groundwater. The mixing calculations are based in understanding of hydrological changes in the past in combination with mixing and mass balance calculations. Examples of baseline parameters are furnished in Table A-6.

Long-term monitoring entails recurrent tracking of the water composition in a number of observation points consisting of wells, soil pipes, percussion boreholes and sections in cored holes. The data are useful to increase the scientific understanding of the site, but also to provide input for engineering, for safety and performance analyses, Table A-6. The high-quality measurement and interpretation of groundwater chemistry is crucial for later constraining the groundwater flow models, c.f. Figure 5-8. It is also essential that data collection, data interpretation and evaluations are integrated with the hydraulic programme and also make full use of the records for site investigations, repository construction and other man-made impacts, Table A-1.

Hydrogeochemical monitoring actions during the site investigations includes repeated surface water sampling, as mentioned in Section 5.3.2 and groundwater sampling in boreholes, as mentioned in Section 5.3.5.

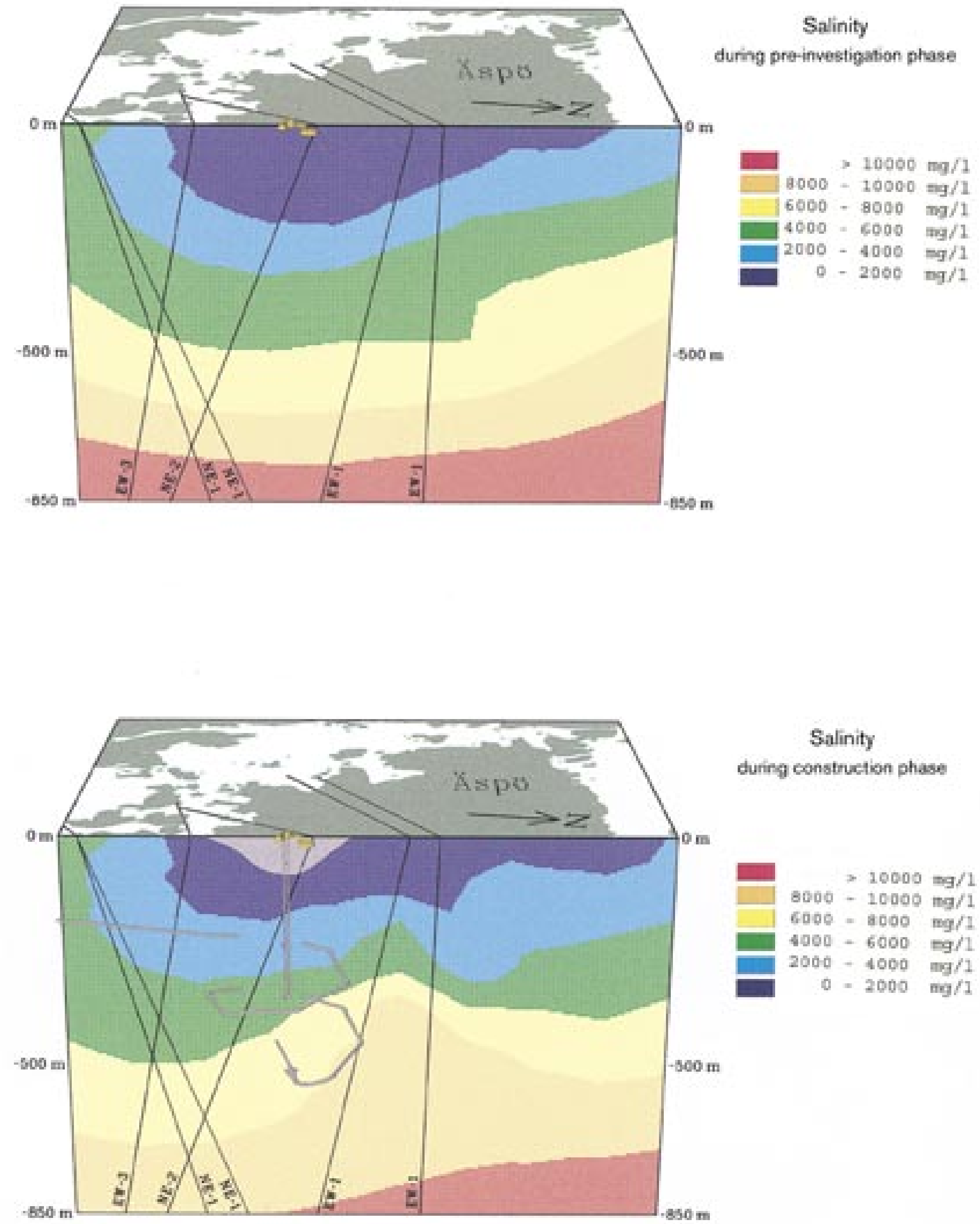

Figure 5-8. *Illustration of how monitoring of groundwater chemistry is used to construct site models. The picture shows the salinity distribution at the Äspö island. The upper picture shows the Primary Baseline before constructing the Äspö Hard Rock Laboratory. The picture below shows the salinity distribution after construction was completed.*

5.3.7 Transport of solutes

The work on transport of solutes is rather measurements of material parameters than monitoring. The discipline-specific goals are to describe groundwater flows on the deposition hole scale, q, transport resistance, F, diffusivity and matrix porosity of the rock mass, D_e and ε_r and sorption properties (sorption coefficients) for the different substances that may be transported with the groundwater. However, the repeated measurements of groundwater flows in monitored boreholes are regarded as monitoring both for the hydrogeology and the transport property subject areas.

5.3.8 Monitoring of occupational safety and environmental control programme during the site investigations

SKB pursues a well thought out quality system during the planning and execution of the site investigations. Occupational safety is the responsibility of each supplier, but SKB is responsible for co-ordination. One concern is noise from core drilling and noise from drilling is measured, but more as singular reference measurements at the onset of drilling rather than regular monitoring.

With respect to environmental control, SKB has an environmental control programme where different checklists are available for different types of tasks. Before for example core drilling starts, photo documentation of the site is arranged and reference samples collected of soil and groundwater chemistry. During drilling, groundwater levels, water temperature and electrical conductivity of water are monitored. The instructions also call for premeditated actions to mitigate environmental damage depending on monitoring results.

5.4 Identification on methods to be used for monitoring

The site characterisation programme /SKB, 2001b/ with references includes descriptions of the methods used to establish the Primary Baseline. The descriptions include methods for characterisation as well as for modelling and analyses of data. Instruments in use are described in /SKB, 2000/. Life Cycle Costs (LCC) including design, purchase, operation and maintenance/replacement and recycling of monitoring systems have not yet been calculated.

5.5 Identification of the duration and frequency of monitoring, including criteria for when monitoring may terminate

The present current investigation programme does not clearly establish duration, frequency of monitoring for all parameters or criteria for ceasing to monitor parameters. This is reasonable due to the early stage of investigations (March 2004) and it is foreseen that the monitoring programme is more stringent when the construction phase is imminent. Table 5-2 provides general information for a few selected parameters.

Table 5-2. Examples on duration and frequency of monitoring for selected parameters during the site investigation phase.

Issue	Planned duration	Frequency
Man-made inpact		
Industries, type&location	Not decided	Annually
Geology		
Seismic network	Not decided	Event-triggering on line
Hydrogeology		
Groundwater pressure in cored boreholes	Entire site investigation phase	User defined event-logging (down to once every two second) for changes > 2 kPa, or every hour, if less change is detected
Hydrogeochemistry		
Sampling of core boreholes, Class 3 and Class 5 Surface water	Entire site investigation phase	Semi-annually
Occuaptional safety and environmental impact		
Groundwater levels, pH, water temperature, etc during core drilling	Until groundwater levels is restored	24 h

5.6 Reporting of results of monitoring

Reporting of monitoring results is integrated with reporting of other site investigation data. Results from environmental monitoring are supplied to the municipality and the county in accordance with decision by consultation.

The SKB's system for management and quality is shown in Figure 5-9. At the top are policies and corporate procedures for such functions as purchasing, accounting, internal audit, non-conformance management and project control. In addition there are department-specific procedures and, for major projects such as the ongoing site investigations, project manuals are compiled for management of the project. The manuals contain instructions on how project operations are to be conducted and documented. Organisation, responsibilities and powers for different positions, how decisions are made and how reports are to be approved are examples of the contents of these instructions. As regards the technical operation, the manual provides information on what controlling and accounting documents are to be used, see also the report /SKB, 2000/ for details.

The data collected are used to prepare site-descriptive models that are devised and updated stepwise as the investigation progress. Strict model version management is applied to maintain traceability and consistency within and between different disciplines. The Figure 5-10 is an example to show the flow for how the site-descriptive model for hydrochemistry develops from the initial site investigation phase (Model Version 1.2) to the complete site investigation phase (Version 2.x). Open progress reports are prepared in advance of the decision-points in the programme; however it is not planned in detail how the monitoring results will be reported.

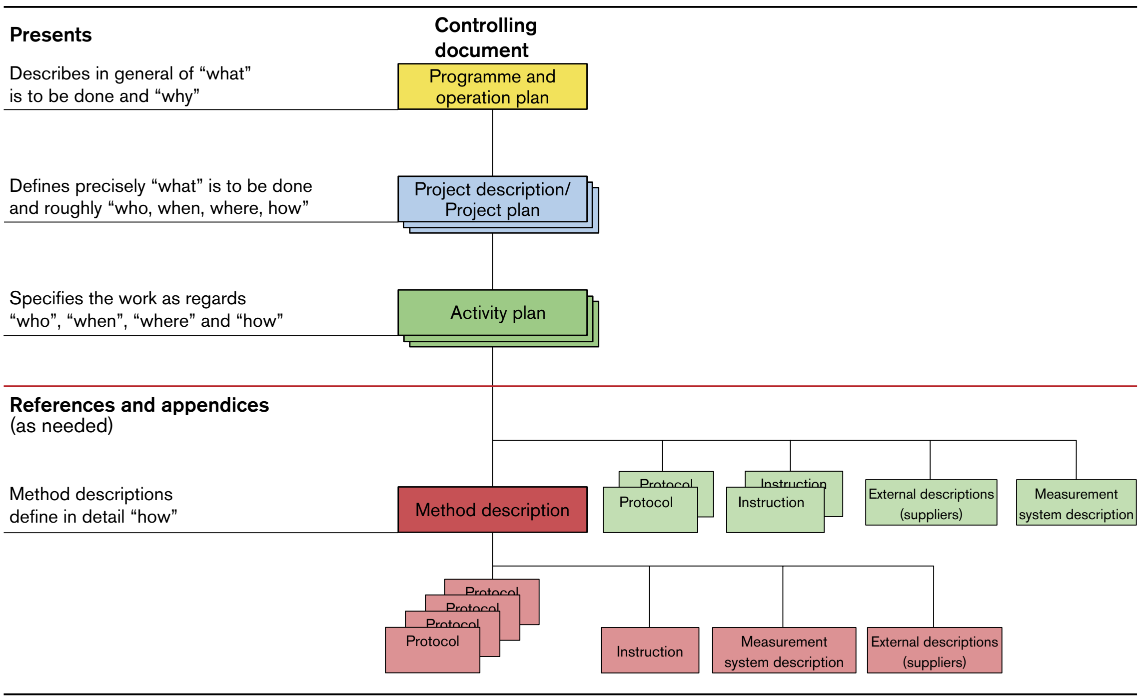

Figure 5-9. Schematic overview of documents for control of the execution of the site investigations, including the monitoring.

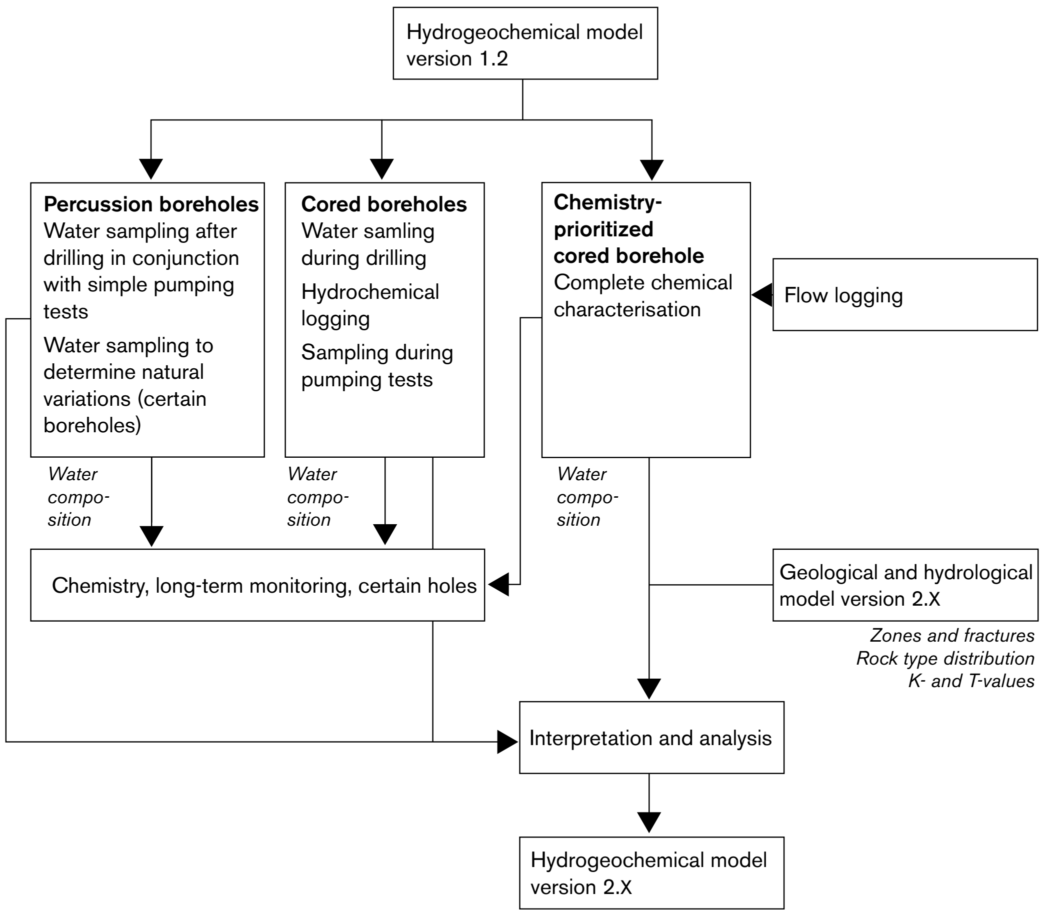

Figure 5-10. Flow plan and information to update the site-descriptive models for hydrogeochemistry during the complete site investigations /SKB, 2001b/.

5.7 Trigger level for actions

SKB now is in the process of establishing the Primary Baseline data and changes are mainly natural fluctuations that are to be recorded "as is" without any need to trigger actions. As mentioned earlier the monitoring of groundwater pressures is automatically event-triggered for certain levels of change. The monitoring points that are connected on-line in real time are of course systematically checked so malfunctioning monitoring components expediently are repaired or replaced.

Trigger levels are to some extent defined in the environmental control programme for the site investigations.

5.8 Actions to be pursued in case of trigger levels exceeded

While there are no definite trigger levels defined in the site investigation phase there are no contingency plans prepared for peculiar monitoring data. During the site investigation several types of data are cross-examined to evaluate the suitability of the candidate sites for a deep geological repository and thorough analyses will be prepared to continue investigations to resolve any outstanding issues, to submit an application to site and construct the deep repository or to abandon the site due to its deemed unsuitability.

6 Discussion

The recent safety standards from IAEA on geological repositories now suggest that a monitoring programme for the deep repository is a requirement prior to and during the operation of the repository. This is not contradictory with SKB's intention to integrate monitoring as an intrinsic activity in the site-characterisation programme in the pre-operation period. However it is helpful to further elucidate how monitoring will be managed during the site investigations and construction of the repository.

Primary Baseline conditions

The first part of a monitoring programme is to establish the Primary Baseline conditions for monitoring where "undisturbed data" are collected. In view of the difficulties to collect these data in the later phases when conditions are perturbed, the Primary Baseline conditions should not only cover the necessary and sufficient data for the next step in the repository implementation, but ideally also cover the possible needs for baseline data in later phases, including repository closure. It is of special concern that data are traceable and transparent so they are useful also for very late phases that may be accomplished several decades later. The present monitoring programme is in its early stages and clarifications concerning duration and frequency on monitoring and reasons to terminate monitoring are to be documented.

SKB has gained substantial previous experience of establishing Primary Baseline conditions, not the least during the site investigations prior to constructing the Äspö Hard Rock Laboratory.

Understanding of the site and the engineered barriers

Establishment of Primary Baseline conditions and monitoring of changes to surface ecosystems and bedrock conditions during the repository construction phase provides data to test and develop the understanding of the site. This understanding is used to detail the evaluations of long term safety, to adapt the repository to the site conditions at hand and also possibly to fine-tune the construction and deposition procedures.

During the initial operation phase and regular operation phase, site characterisation and construction continues with ongoing work to deposit the spent fuel canisters. It is still a matter of discussion how monitoring during the operation of the repository can contribute to the programme. Current idea is that monitoring is "passive" to verify that requirements are met and to adapt the repository layout to the rock conditions at hand rather than being "active", where monitoring results are used to optimise e.g. the buffer and backfill design for long term safety purposes. Monitoring of canister and buffer and near-field rock behaviour can be ruled out at the present level of technology as such systems likely impair the barrier function by adding stray material and formation of potential pathways in the barriers. Such systems are also precarious from operational aspects as the installation and maintenance of the equipment likely increase the radiation dose to the personnel.

SKB has acquired considerable experience of monitoring to develop understanding of a site and engineered barriers. Construction of SFR and CLAB in a nuclear regulatory context and construction of Äspö HRL in an R&D environment are indispensable. The execution of the Prototype Repository Experiment at Äspö HRL and similar experiments elsewhere are indispensable for the future advanced monitoring of the external repository environment and its temporal evolution that is fundamental for the internal processes in the engineered barriers.

Decision-making process

As described before, the implementation of the geological repository is a stepwise process where stakeholders are either required or encouraged to provide input to the decision-process and where decisions are on several levels. From the definition of monitoring adopted – *"Continuous or repeated observations or measurements of parameters to increase the scientific understanding of the site and the repository, to show compliance with requirements or for adaptation of plans in light of the monitoring result."* we understand that monitoring may be used for scientific, regulatory or managerial decisions.

With respect to the scientific decisions related to the long-term safety it is here suggested that monitoring results themselves are indicators only and that there should be very few implementation decisions based on the results solely. The reason is that major decision points in the programme are preceded by comprehensive, updated safety assessments using where the importance of a monitoring result as well as other data is put in a holistic perspective.

Repository safety and performance cannot be directly monitored, but it would be of great significance if key indicators are determined where lumping of one or several measured parameters constitute a basis for tracking the pre- and post-closure performance of the repository during the repository implementation.

In case of compliance monitoring, the monitoring data are of tremendous value to ascertain that the work is conducted within the existing regulations and permits. As for any monitoring it is if importance that data are indisputable.

From a management perspective monitoring will be used to adapt the plans based on the results. Data may be used to adjust locations, types of monitoring as well as frequency and duration of monitoring etc as well as other elements in the monitoring programme as discussed in the Chapter 4.2. Monitoring results will be used to steadily improve the operational safety including efforts to lower any possible radiological impact to the personnel.

Much thought over the years have been devoted to the decision-making process for post-closure monitoring. It is here suggested that the concept of post-closure is broadened as the repository stepwise is closed and stepwise enters periods of post-closure with institutional control. The first such closure is the sealing of a backfilled tunnel, the next likely to be connected to a licensing situation is the closure of the first deposition area. Here we can think of a post-closure care period including monitoring and safeguarding for the series of deposition areas constructed and sealed-off before the whole repository is closed. SKI acknowledges in the comments to the regulations that measures can be adopted during construction and operation for the possible monitoring of a repository's integrity and its barrier performance after closure but also demand that barriers can provide the required safety without monitoring or maintenance after the repository is closed. Any such system requires that operation and maintenance of the system can be carried out from surface and in case boreholes are used there would be no safety concern regarding the effects of the surface boreholes.

Compliance with guidelines and regulations

Although much of the discussions on monitoring relate to long term safety, the significance of monitoring to ensure high standard of construction and operational safety, should not be underestimated. There are no reasons to believe that operating an underground repository would be much safer than to operate an underground mine as both activities involve considerable traffic with heavy vehicles and handling of heavy materials.

Besides operational monitoring it is of paramount importance to monitor the environmental impact and ensure that the work complies with the stipulated conditions in regulations and permits. SKB wants to limit the environmental impact of the deep repository and environmental monitoring will be essential to fulfil this ambition.

SKB has gained comprehensive experience from environmental monitoring from the construction and operation of its facilities.

7 Conclusions

The international and national regulatory framework on monitoring advocates monitoring at all stages of the repository implementation with the limitation that closed repository shall not be dependent on monitoring or maintenance for its safety. Any measures to monitor should either have a minor or negligible impact on repository safety, or that the measures result in an improvement of safety, compared with the situation that would arise if the measures were not adopted.

SKB has over a range of years accumulated extensive experience to monitor underground non-nuclear and nuclear facilities. The monitoring is concerned with bedrock conditions before and during construction and operation of the facilities, active design to engineer the underground facilities based on monitoring results during construction, the safe and environmental construction and operation of facilities, monitoring of barrier function at SFR, the final repository for low – and intermediate level waste and at the Äspö Hard Rock Laboratory and monitoring for safeguard at CLAB, the interim storage for spent nuclear fuel. The know-how relates to all aspects from design, installation, operation and maintenance to decommissioning of systems. Useful and feasible sensors and communication systems are available to monitor safety-relevant issues. Routines are available to ensure monitoring data are relevant, quality assured, traceable and transparent.

It is natural that the development of a monitoring programme is stepwise and closely tied to the major decision-points in the implementation programme for the deep repository. As an overall strategy it is vital that monitoring be well integrated into the general plans rather than being a separate activity. The ongoing site investigations with an inherently integrated monitoring programme clearly benefits from this approach.

There are of course still many open questions to address, not the least concerning monitoring of the open repository to collect data to verify barrier performance before closing the repository. Repository performance and safety cannot be directly monitored, but it would be of great significance that key indicators are determined to constitute a basis for tracking the performance of the repository during the repository implementation.

It is foreseen that philosophy and monitoring procedures for the post-closure phase will develop as the implementation programme moves ahead. It is appropriate that any decisions on post-closure monitoring are taken by the generation that is the decision-maker at the time of closure. While the responsibility for the repository is transferred to the State after closure it is then also needed to clarify the responsibility for execution of the post-closure monitoring

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ANNEXES – Establishing Primary Baseline Conditions for monitoring. Tables on possible processes/features and parameters to monitor and rationales for their monitoring

Table A-1. Examples of baseline conditions possible for monitoring – Man-made Impact.

Primary Baseline Conditions – Man-made Impact			
PROCESS/FEATURE	**PARAMETERS**	**RATIONALE** **1. Input for engineering, safety and performance analyses** **2. Environmental impact** **3. External, local effects on baseline conditions**	**COMMENTS**
Traffic			
	# and type of vehicles	R2, R3	
	Noise	R2, R3	
	Accidents	R2	
Deposit of excavated rock			
	Visual impression	R2	

Primary Baseline Conditions – Man-made Impact			
PROCESS/FEATURE	**PARAMETERS**	**RATIONALE** **1. Input for engineering, safety and performance analyses** **2. Environmental impact** **3. External, local effects on baseline conditions**	**COMMENTS**
	Volume of rock	R2	
	Areal extent	R2, R3	
	Chemistry of leachates	R2, R3	
Industry			
	Type and extent of industries	R2, R3	
Pollution sources			
	Local industries, domestic housing and traffic	R2, R3	

Primary Baseline Conditions – Man-made Impact			
PROCESS/FEATURE	**PARAMETERS**	**RATIONALE** **1. Input for engineering, safety and performance analyses** **2. Environmental impact** **3. External, local effects on baseline conditions**	**COMMENTS**
	Regional/global	R2, R3	In Sweden: Monitored by the Environmental Protection Agency
Roads			
	Location, extent	R2, R3	
Railways			
	Location, extent	R2, R3	
Tunnels			
	Location, extent	R2, R3	
Mines			

Primary Baseline Conditions – Man-made Impact			
PROCESS/FEATURE	**PARAMETERS**	**RATIONALE** **1. Input for engineering, safety and performance analyses** **2. Environmental impact** **3. External, local effects on baseline conditions**	**COMMENTS**
	Location, extent	R2, R3	
Power lines			
	Location, extent	R2, R3	
Ditches			
	Location, extent	R2, R3	
Wells			
	Location, extent	R1, R2, R3	
Potable water resources			
	Location, extent	R2, R3	

Primary Baseline Conditions – Man-made Impact			
PROCESS/FEATURE	**PARAMETERS**	**RATIONALE** **1. Input for engineering, safety and performance analyses** **2. Environmental impact** **3. External, local effects on baseline conditions**	**COMMENTS**
Population			
	Migration	R1, R2, R3	
	Permanent	R1, R2, R3	
	Visitors	R1, R2, R3	
Protected archaeological and historical objects			
	Confirming non-impact by repository implementation	R2	
Protected areas			
	Extent	R1, R3	

Primary Baseline Conditions – Man-made Impact			
PROCESS/FEATURE	**PARAMETERS**	**RATIONALE** **1. Input for engineering, safety and performance analyses** **2. Environmental impact** **3. External, local effects on baseline conditions**	**COMMENTS**
Buildings			
	Location and extent	R2, R3	
Implementation for repository			
	Records of site characterisation activities	R1, R2, R3	R3 Needed to interpret disturbances in measurements

Table A-2. Examples of baseline conditions possible for monitoring – Surface Ecosystem.

Primary Baseline Conditions - Surface Ecosystem			
PROCESS /FEATURE	**PARAMETERS**	**RATIONALE** **1. Input for engineering, safety and performance analyses** **2. Environmental impact** **3. External, local effects on baseline conditions**	**COMMENTS**
Forestry		R1, R2	C1 Carbon-turnover models
	Total volume		
	Growth rate		
	Turnaround time		
	Age structure		
Agriculture		R1, R2	C2 Human/Biota uptake
	Growth rate of crops		
	Stock of animals		

Primary Baseline Conditions - Surface Ecosystem

PROCESS /FEATURE	PARAMETERS	RATIONALE 1. Input for engineering, safety and performance analyses 2. Environmental impact 3. External, local effects on baseline conditions	COMMENTS
	Agricultural land		
Fishing/Hunting		R1, R2	C1+C2
	# of recreational fishing licences		
	Catch of fishes		
	# of professional fishermen		
	Catch ration		
	Hunting ration		
	Hunting statistics		
Recreational activities		R1, R2	C3 Human uptake
	# of daily visitors		

Primary Baseline Conditions - Surface Ecosystem

PROCESS /FEATURE	PARAMETERS	RATIONALE 1. Input for engineering, safety and performance analyses 2. Environmental impact 3. External, local effects on baseline conditions	COMMENTS
Water balance		R1, R3	C4 Radionuclide flow; C5 Model confidence
	Precipitation -rain -% as snow		
	Run-off		
	Evapotranspiration		
	Irrigation		
Climatic variations		R1, R3	
	Air temperature		

Primary Baseline Conditions - Surface Ecosystem

PROCESS /FEATURE	**PARAMETERS**	**RATIONALE** **1. Input for engineering, safety and performance analyses** **2. Environmental impact** **3. External, local effects on baseline conditions**	**COMMENTS**
	Ice conditions -date for freeze-up -date for break-up		
	Ground frost - seasonal variation in extent and depth		
	Wind direction		
	Wind speed		
	Air pressure		
	Sun insolation		

Primary Baseline Conditions - Surface Ecosystem

PROCESS /FEATURE	PARAMETERS	RATIONALE 1. Input for engineering, safety and performance analyses 2. Environmental impact 3. External, local effects on baseline conditions	COMMENTS
	Direct radiation, including cosmic component		
Scenery		R2	
	Visual impression (# of photographs)		
Soil/Quaternary deposits		R1	
	Soil type		
	Thickness		
	Chemistry		

Primary Baseline Conditions - Surface Ecosystem

PROCESS /FEATURE	PARAMETERS	RATIONALE 1. Input for engineering, safety and performance analyses 2. Environmental impact 3. External, local effects on baseline conditions	COMMENTS
Toxic concentration in biotopes		R1	
	Toxic contents in flora, fauna		
Nuclide concentration		R1	
	Local dose rate		Average radiological burden of the local population
Flora		R2	
	Type of vegetation		
	Growth rate		
	Protected species		

Primary Baseline Conditions - Surface Ecosystem			
PROCESS /FEATURE	**PARAMETERS**	**RATIONALE** **1. Input for engineering, safety and performance analyses** **2. Environmental impact** **3. External, local effects on baseline conditions**	**COMMENTS**
Faunae		R2	
	Population		
	Protected species		
Lakes/Streams		R1	
	Type of sediments		
	Sediment composition		
	Sediment chemistry (several parameters, c.f. /SKB, 2001b/)		
	Water levels		
	Turnover (lakes)		
	- Water chemistry (several parameters, like oxygen,		

Primary Baseline Conditions - Surface Ecosystem

PROCESS /FEATURE	PARAMETERS	RATIONALE 1. Input for engineering, safety and performance analyses 2. Environmental impact 3. External, local effects on baseline conditions	COMMENTS
	radionuclide concentration etc., c.f. /SKB, 2001b/.		
	Oxygen uptake		
	Stratification		
	Visibility		
	Temperature		
	Run-off (streams)		
Marine waters		R1, R3	
	Turnover		
	Currents		
	Water level		

Primary Baseline Conditions - Surface Ecosystem

PROCESS /FEATURE	**PARAMETERS**	**RATIONALE** **1. Input for engineering, safety and performance analyses** **2. Environmental impact** **3. External, local effects on baseline conditions**	**COMMENTS**
	Sediment types		
	Sediment composition		
	Sediment chemistry (c.f. /SKB, 2001b/.)		
	Oxygen concentration		
	Oxygen uptake		
	- Water chemistry (oxygen, radionuclide concentration, salinity, etc., c.f. /SKB, 2001b/.)		
	Toxic concentration		
	Stratification		

Primary Baseline Conditions - Surface Ecosystem			
PROCESS /FEATURE	**PARAMETERS**	**RATIONALE** **1. Input for engineering, safety and performance analyses** **2. Environmental impact** **3. External, local effects on baseline conditions**	**COMMENTS**
	Visibility		
	Temperature		
Unsaturated zone/Groundwater		R1, R3	
	Groundwater table variations		
	Water chemistry (c.f. /SKB, 2001b/)		
	Well capacities		
	# of wells		
Local dose rate			
	Average radiological burden of the local population		

Table A-3. Examples of baseline conditions possible for monitoring – Geology.

Primary Baseline Conditions - Geology			
PROCESS/FEATURE	**PARAMETERS**	**RATIONALE** **1. Input for engineering, safety and performance analyses** **2. Environmental impact** 3. **External, local effects on baseline conditions**	**COMMENTS**
Geothermal conditions		R1, R2, R3	
	Regional subsurface temperature field in rock		
	Heat flow density at surface		
	Thermal boundary conditions/gradient		
Seismic activity		R1	
	Hypocenter		
	Magnitude		
	Seismic moment		

Primary Baseline Conditions - Geology			
PROCESS/FEATURE	**PARAMETERS**	**RATIONALE** **1. Input for engineering, safety and performance analyses** **2. Environmental impact** 3. **External, local effects on baseline conditions**	**COMMENTS**
Aseismic creep		R1	
	Strain as measured by GPS		
	Precision levelling		
	Uplift measurements		
	Trilateration measurements		

Table A-4. Examples of baseline conditions - Rock Mechanics (possibly for monitoring).

Primary Baseline Conditions - Rock Mechanics			
PROCESS/FEATURE	**PARAMETERS**	**RATIONALE** **1. Input for engineering, safety and performance analyses** **2. Environmental impact** **3. External, local effects on baseline conditions**	**COMMENTS** The parameters may be a part of the monitoring programme prior to construction.
Rock Stress			
	In-situ stress field magnitude, direction	R1 .	Stress change monitoring is also useful to determine rock support, evaluation of thermal load etc.
Dynamic Propagation Velocity	Pressure and shear wave	R1	Indicator for stress changes or change in saturation (pressure wave)

Table A-5. Examples of baseline conditions possible for monitoring – Hydrogeology.

Primary Baseline Conditions - Hydrogeology			
PROCESS/FEATURE	**PARAMETERS**	**RATIONALE** **1. Input for engineering, safety and performance analyses** **2. Environmental impact** **3. External, local effects on baseline conditions**	**COMMENTS**
Groundwater pressures		R1, R2, R3	
	Water table		
	Infiltration in bedrock		
	Density (salinity) distribution of water		
	(Absolute) Pressures in deep boreholes		
	Temperature of water in deep boreholes		

Primary Baseline Conditions - Hydrogeology			
PROCESS/FEATURE	**PARAMETERS**	**RATIONALE** **1. Input for engineering, safety and performance analyses** **2. Environmental impact** **3. External, local effects on baseline conditions**	**COMMENTS**
	Uplift		
	Sea level changes		
	Earth tide		
	Air pressure		
Groundwater flow		R1	
	Flow in boreholes		

Table A-6. Examples of baseline conditions possible for monitoring - Hydrogeochemistry.

Primary Baseline Conditions - Hydrogeochemistry			
PROCESS/FEATURE	**PARAMETERS**	**RATIONALE** **1. Input for engineering, safety and performance analyses** **2. Environmental impact** 3. **External, local effects on baseline conditions**	**COMMENTS**
Chemical and microbial composition in cored boreholes (> 200 m in depth) and shallow percussion boreholes (0-200 m in depth)	***Split into usage***		As the basis to understand ongoing processes (e.g. mixing). /Rhén et al, 1997; SKB, 2001b/
	For spent fuel		
	pH, Eh, Fe^{2+}, HS^-	R1	
	For copper canister		
	pH, Eh, Fe^{2+}, HS^-, Cl^-, NO_2^-, NO_3^-, NH_4^+	R1	

Primary Baseline Conditions - Hydrogeochemistry

PROCESS/FEATURE	PARAMETERS	RATIONALE **1. Input for engineering, safety and performance analyses** **2. Environmental impact** 3. **External, local effects on baseline conditions**	COMMENTS
	For buffer		
	pH, K^+, Na^+, Ca^{2+},Mg^{2+}, TDS	R1	TDS (Total Dissolved Solids)
	For nuclide retention		
	pH, Eh, Fe^{2+},HS^-,HCO_3^-, Cl^-, Na^+, Ca^{2+},HA/FA, dissolved gases N_2, H_2, CO_2, CH_4, He, Ar, colloids and bacteria	R1	
	For geochemical understanding		
	Electrical conductivity	R1	
	pH, Eh	R1	

Primary Baseline Conditions - Hydrogeochemistry

PROCESS/FEATURE	PARAMETERS	RATIONALE **1. Input for engineering, safety and performance analyses** **2. Environmental impact** 3. **External, local effects on baseline conditions**	COMMENTS
	Main constituents (Na, K, Ca, Mg, Fe, Mn, Li, Sr, Si, HCO_3, SO_4, Cl), Uranine (or tracer used to tag drilling water)	R1	
	Trace elements (Fe, Mn, U, Th, Ra, Si, Al, Li, Cs, Sr, Ba, HS, I, Br, F, PO_4, NO_2, NO_3 and/or NO_2+NO_4, DOC)	R1	DOC (Dissolved Organic Carbon)
	Dissolved gases (N_2, H_2, CO_2, CH_4, Ar, He)	R1	
	Stable isotopes (^{18}O, ^{2}H, ^{3}H in H_2O, ^{13}C in DIC and DOC, ^{34}S and ^{18}O in SO_4 and HS, $^{87}Sr/^{86}Sr$, ^{3}He, ^{4}He	R1	DIC (Dissolved Inorganic Carbon)

Primary Baseline Conditions - Hydrogeochemistry

PROCESS/FEATURE	PARAMETERS	RATIONALE **1. Input for engineering, safety and performance analyses** **2. Environmental impact** 3. **External, local effects on baseline conditions**	COMMENTS
	Radioactive isotopes (^{3}H, ^{14}C in DIC and DOC, $^{234}U/^{238}U$, ^{36}Cl)	R1	
	Bacteria	R1	
	Minerals: Soluble, reactive that show the development in the area	R1	
	Archive samples of acidified and unpreserved frozen samples	R1, R3	
	Options Isotopes δ^{34} S (in SO_4), $\delta^{37}Cl$, $\delta^{87}Sr$, $\delta^{10}B$	R1	Rows below are possible options
	^{14}C pmc (% modern carbon), $\delta^{13}C$	R1	

Primary Baseline Conditions - Hydrogeochemistry

PROCESS/FEATURE	PARAMETERS	RATIONALE **1. Input for engineering, safety and performance analyses** **2. Environmental impact** 3. **External, local effects on baseline conditions**	COMMENTS
	^{226}Ra, ^{228}Ra and ^{222}Rn	R1	
	Isotopes of U and Th	R1	
	Trace metals	R1	
	Dissolved gases (incl. $\delta^{18}O$, $\delta^{13}C$, $^{3}He/^{4}He$)	R1	
	Bacteria	R1	
	Colloids	R1	
	Humus and fulvic acids	R1	
	pH and Eh measurements on-line.	R1, R3	

Primary Baseline Conditions - Hydrogeochemistry

PROCESS/FEATURE	PARAMETERS	RATIONALE **1. Input for engineering, safety and performance analyses** **2. Environmental impact** 3. **External, local effects on baseline conditions**	COMMENTS
Chemical and microbial composition in wells	Electrical conductivity, pH, Cl, HCO_3, SO_4, Br, Uranine (or tracer used to tag drilling water), temperature, cations (Na, K, Ca, Mg, Li, Sr, Si) and SO_4	R1	C.f. /SKB, 2001b/
	Options: Archiving of frozen samples	R1	Rows below are possible options
	δ^2H, ^3H, $\delta^{18}O$	R1	δ denotes fraction of specified isotope to the total content of the element
	δ^{34} S (in SO_4), $\delta^{37}Cl$, $\delta^{87}Sr$, $\delta^{10}B$	R1	
	^{14}C pmc (% modern carbon), $\delta^{13}C$	R1	

Table A-7. English-Swedish glossary.

ENGLISH	Definition	SVENSKA	Betydelse
Boundary conditions, intial conditions	Conditions accompanying a differential equation in the solution of physical problems. The solution and its derivatives must satisfy conditions either describing the influence from outside the region (boundary values) or giving information about the solution at a specified time (initial values)	Randvillkor, begynnelsevillkor	Villkor tillhörande en differentialekvation vid lösning av ett fysiskt problem. Lösningen och dess derivator måste uppfylla villkor som antingen beskriver inflytande utanför området (randvillkor) eller ge information om lösningen vid en speciell tid (begynnelsevillkor)
Monitoring	Continuous or repeated observations or measurements of parameters to increase the scientific understanding of the site and the repository, to show compliance with requirements or for adaptation of plans in light of the monitoring results	Långtidsobservationer	Sammanhängande eller upprepade observationer eller mätningar av parametrar för att öka den vetenskapliga förståelsen för platsen och förvaret, för att visa att ställda krav är uppfyllda för att anpassa planerna till resultaten
Primary baseline	Site-specific conditions prior to start of construction of the repository (before going underground)	Primära jämförelsedata	Platsspecifika förhållanden före förvarets byggstart.
Trigger level	Pre-determined value for a specific action	Tröskelvärde	Förutbestämt värde för en särskild åtgärd