SURVEILLANCE OF A DEEP GEOLOGICAL REPOSITORY FOR RADIOACTIVE WASTE

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ABSTRACT

In connection with the revision of the nuclear energy law in Switzerland, the "Expert Group on Disposal Concepts for Radioactive Waste (EKRA)" has evaluated various options for long-term management of both L/ILW and HLW. The expert group has concluded that passively safe disposal in a deep underground repository is the only method for isolating radioactive waste which fulfils the requirement for long-term safety. The group also concluded that social demands concerning waste disposal are oriented towards the principle of reversibility. Their concept of monitored long-term geological disposal takes into account requirements for long-term safety and reversibility, including monitoring.

The primary objectives for monitoring a nuclear waste repository are (i) to complement data (by periodic or continuous measurements following initial site investigations) for use in repository design and construction and for use in the long-term safety assessment, (ii) to collect data (before repository closure) to determine the radiological and non-radiological impacts of the repository on the operating personnel, the general population and the natural environment, in order to demonstrate compliance with regulatory requirements, and (iii) to provide information that will assist in the decision-making process leading up to repository closure. Post-closure monitoring may play a role in maintaining the confidence of future generations in the adequacy of the repository and ensuring long-term security for fissile materials.

Monitoring is considered as a component of a wider strategy, consisting of a surveillance plan, a decision-making process (based on adequate criteria) and an appropriate scheme for actions and measures - where "proceed as foreseen towards repository closure" is the most probable case. The surveillance scheme, however, will not exempt the implementer from demonstrating the safety of the disposal system prior to waste emplacement, and any monitoring actions or complementary measures must not compromise long-term safety.

INTRODUCTION

"Monitoring", or the issue of "surveillance" in general, has become an important aspect of the implementation process of a geological repository for radioactive waste. Besides technical issues, societal demands and expectations also need to be considered when defining what monitoring actions are feasible and practicable and what is necessary. Monitoring strategies have been widely discussed within international working groups (e.g. the International Atomic Energy Agency [1], Concerted Action of European Commission [2]).

Monitoring is often defined as the periodic or continuous determination of the status of specific components of the repository system by means of appropriate measurements and observations (as opposed to one-time measurements). The nature of these measurements will depend on the geological environment and the details of the disposal concept.

Discussions among various stakeholders (i.e. implementers, regulators, environmental organisations, politicians, general public) about the objectives and the contents of monitoring strategy are continuing. Bearing this in mind, the immediate definition of a detailed and complete surveillance programme is probably premature, even though the methodologies that are likely to be adopted are mostly common practice, i. e. they are strongly based on the requirements and experience of monitoring activities in other nuclear facilities, standard practice for environmental (radiological and non-radiological) monitoring and earth-scientific investigation methods that either exist or are currently under development.

The present paper aims to provide a contribution to the discussion of the basic principles of monitoring, based on the experience in the Swiss disposal programme. Monitoring is hereby put in a wider context, namely into the framework of surveillance, the decision-making process and - if necessary - measures and actions.

STRATEGY FOR THE DISPOSAL OF RADIOACTIVE WASTE IN SWITZERLAND

According to Swiss law, the producers of nuclear waste are themselves responsible for its safe management. Hence, in 1972 the electricity supply utilities, which operate five nuclear power plants (with a total capacity of 3 GW_e), and the Federal Government (responsible for the wastes from medicine, industry and research) formed the National Cooperative for the Disposal of Radioactive Waste (Nagra). Nagra is responsible for preparing for the disposal of all categories of waste.

In the Swiss disposal concept, two types of repository are foreseen, namely

- the repository for low- and intermediate-level waste (L/ILW) arising from the operation and decommissioning of Swiss nuclear power plants and from medicine, industry and research, as well as for low-level technological waste from reprocessing. The repository will consist of mined caverns with horizontal access, located in a suitable geological formation;
- the repository for vitrified high-level waste (HLW), long-lived intermediate-level waste (TRU, primarily resulting from fuel reprocessing) and for direct disposal of spent fuel elements. The repository will be located in a deep geological formation and will consist of a drift system for in-tunnel emplacement of HLW and spent fuel and silos or drifts for long-lived intermediate-level waste, with access via a vertical shaft or ramp.

Swiss federal law requires geological repositories even for low-level radioactive waste, therefore, no shallow land burial can be foreseen. Following a long and systematic evaluation procedure and a comprehensive investigation phase, Wellenberg has been proposed as the site for the L/ILW repository. The relevant application for a general licence was submitted to the Federal Government in 1994 by the "Genossenschaft für nukleare Entsorgung Wellenberg" (GNW), which is the site-based construction and operating company. The next stage -

construction of an underground exploratory drift - already has the approval of the Federal Council. Since 1995, however, no progress in the Wellenberg project has been possible because of a cantonal veto on the mining concession for the use of the underground.

For the siting of the HLW/TRU repository, the crystalline basement and sediments (Opalinus Clay) in Northern Switzerland are under consideration. In addition to the possibility of disposing of these wastes within Switzerland, the option of disposal within the framework of multinational projects is also kept open. The repository for HLW and spent fuel will not be required before the middle of this century.

Until such time as the planned repositories become operational, all categories of waste will be held in interim storage. In particular, HLW and spent fuel will be held in interim storage for a period of at least 40 years, in order to allow heat production from the waste to decrease. Storage capacity is presently available at the sites of the nuclear power plants; the centralised interim storage and conditioning facilities (ZWILAG) are also in the start-up phase and will provide storage capacity for spent fuel and wastes from all the Swiss nuclear power plants - including returned reprocessing waste.

MONITORED LONG-TERM GEOLOGICAL DISPOSAL

In connection with the current revision of the Swiss nuclear energy law - and also for the decision on how to proceed with the L/ILW repository project at Wellenberg - in June 1999 the responsible Swiss Minister set up an expert group (EKRA, "Expert Group on Disposal Concepts for Radioactive Waste") to evaluate the options for long-term management of both L/ILW and HLW. The report [3] was presented in early February 2000. It contains some important and far-reaching conclusions and recommendations directly relevant to geological disposal.

The experts have concluded that - based on current knowledge - passively safe geological disposal is the only method for isolating radioactive waste which fulfils the requirement for long-term safety (i. e. for high-level waste up to more than 100,000 years). The disposal concept will therefore be based on a combination of engineered and natural safety barriers, which ensure long-term isolation of the waste. The group also concluded that the social demands concerning waste disposal are oriented towards the principle of reversibility. EKRA has therefore developed the concept of actively managed *monitored long-term geological disposal*, which combines disposal with the possibility of reversibility. The final objective - passive geological disposal - will thus be realised in a stepwise manner. In addition to the actual waste emplacement facility (the main facility) and the test facility (the underground rock laboratory), the concept foresees the construction of a so-called pilot facility and a monitoring phase with facilitated waste retrieval prior to complete closure of the whole facility.

REPOSITORY SURVEILLANCE SCHEME

Swiss legislation requires the safe disposal of radioactive waste, whereby the post-closure safety of the underground disposal system must be independent of any further surveillance. Nevertheless, some monitoring and surveillance activities are foreseen in the operational phase and will also continue after repository closure as long as they are thought to be beneficial to society. However, it has to be ensured that long-term safety is not impaired by monitoring actions or complementary measures, e.g. to facilitate retrieval of the waste.

Considering the results presented in the EKRA report [3], and taking into account the wide international discussion of the topic (see e.g. [4], [5]), Nagra has formulated the primary objectives for monitoring a nuclear waste repository in the following way:

Prior to repository closure

- to complement data (by periodic or continuous measurements following initial site investigations) for use in repository design and construction and for use in the long-term safety assessment; this will include confirmation of some of the conceptual and numerical models developed to describe system behaviour;
- to collect data (before repository closure) to determine the radiological and non-radiological impacts of the repository on the operating personnel, the general population and the natural environment, in order to demonstrate compliance with regulatory requirements;
- in the stepwise process of repository development: to provide information that will assist in the decision-making process (i. e. confidence-building) leading up to repository closure.

For time periods both before and after repository closure

- to address the requirement of safeguards to ensure security (if the repository contains fissile materials such as spent fuel or plutonium-rich waste);
- to maintain the confidence of future generations in the adequacy of the repository.

In addition to the above-mentioned objectives, monitoring is also important - for reasons of liability - to establish base-line conditions at the repository site, including investigation of natural variability of measured parameters, in order to assess any potential radiological and non-radiological impact of underground excavation and repository construction and operation on the geological and surface environments.

When planning the detailed monitoring activities it will be necessary to balance the benefits of gaining additional information against possible detriments from monitoring activities such as:

- radiation dose to monitoring personnel
- degradation of materials resulting from the delayed closure of parts of the repository
- formation of pathways through the barrier system leading to enhanced flow of groundwater within the repository
- enhanced likelihood of human intrusion - especially if the underground structure remains open and society loses interest in institutional control
- stray material in disposal areas (for the same reasons as mentioned above)

Repository surveillance in a general sense covers more than the monitoring activities related to site characterisation, the safe operation of the disposal facility and the evolution of the disposal system. Surveillance will also include a scientific programme in order to keep track of the development of science and technology in the areas relevant to the repository. This may also include laboratory work and in-situ investigations in underground rock laboratories. Furthermore, experience gained in other national disposal projects will also be taken into account. All information available will be periodically evaluated in safety assessment reports for the repository.

A monitoring and surveillance strategy is only sensible if it is complemented by the possibility for corrective measures and actions in case of unexpected (i. e. unpredicted and unacceptable) system behaviour. These actions are based on a decision-making process and may comprise technical (for instance during repository design and construction) as well as administrational measures (during repository operation) and could go as far as to waste retrieval (see schematic overview in Fig. 1).

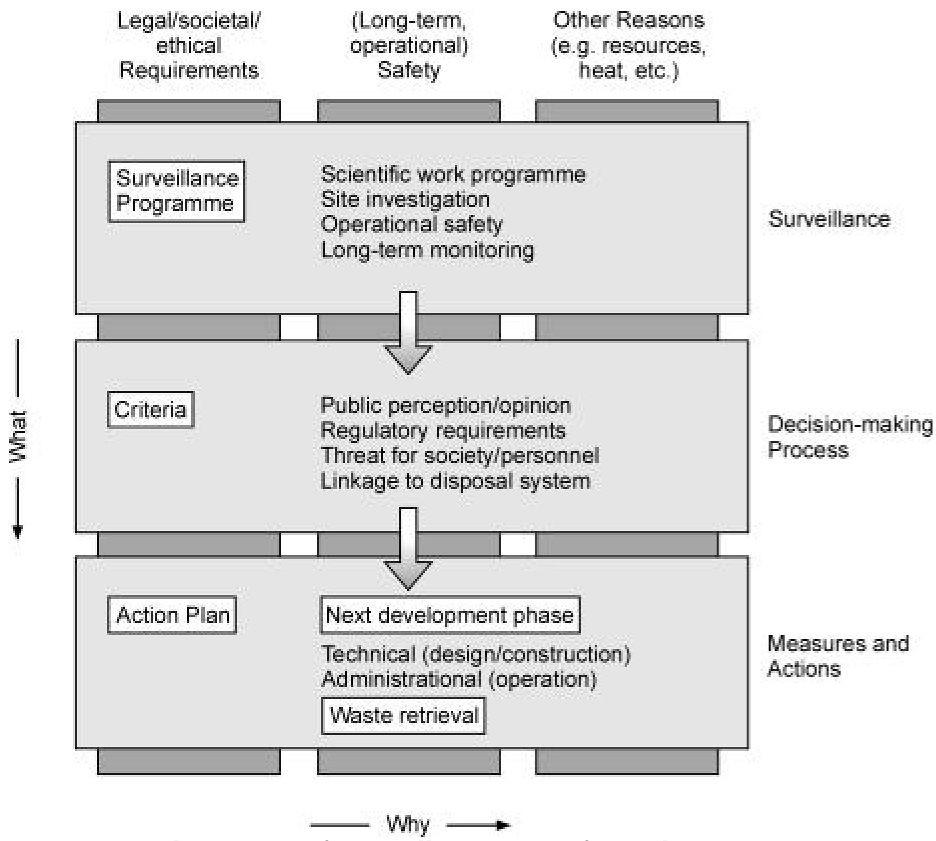

Fig. 1 Implementation of a surveillance strategy for a radioactive waste repository

Under the assumption that the surveillance plan confirms adequate evolution of the disposal system, repository development will proceed according to the original plan.

AN EXAMPLE - THE SWISS L/ILW REPOSITORY PROJECT

Since the veto on the L/ILW repository project in 1995 (see section 2), several working groups have discussed the different options on how to proceed. In March 2000 the Federal Government and the Government of Canton Nidwalden - where the proposed L/ILW repository will be located - agreed that, as a next step, site investigations have to continue and defined the necessary steps. In early June it was agreed that this process will be guided and monitored by a special coordination group. One of the issues to be resolved is the modification of the repository concept according to the concept of monitored geological disposal as proposed by EKRA. The corresponding work has been finalised in the meantime [6] and the resulting repository concept is briefly described below.

Elements of the repository concept

In line with the proposed concept of monitored geological disposal, the facility will consist of the following components

- the main facility
- the test facility
- the pilot facility

An artist's impression of a possible layout of these facilities is shown in Fig. 2.

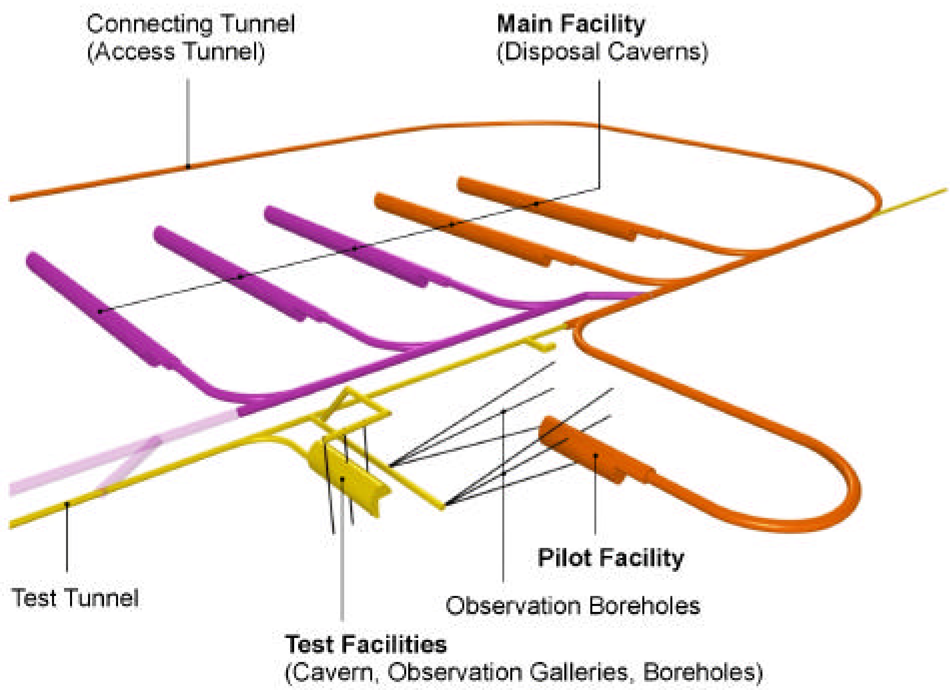

Fig. 2 L/ILW repository with main facility, test facilities and pilot facility

The main facility will contain the bulk of the wastes and will be implemented in such a manner that it will be passively safe; this implies that it will be backfilled and sealed within a reasonable time span after emplacement of the wastes. However, the layout of the facility will also ensure that the waste could be retrieved with reasonable effort if this were required.

The test facility provides the necessary infrastructure for testing the relevant parts of the repository system before actually starting emplacement of any wastes. Thus, it represents those elements of the system which - in similar disposal projects - are termed in-situ rock laboratories, exploratory drifts etc.

The pilot facility provides the infrastructure for collecting information to confirm the performance of the repository system. It should also allow the early detection of any deviations from the expected evolution. The pilot facility will include several experiments, including a pilot cavern. This pilot cavern is a small but representative copy (also in terms of the waste inventory) of a disposal cavern that can be instrumented for long-term observations even after the closure of the main facility.

Stepwise implementation

The repository system as described above will be implemented in a stepwise manner. The different phases and the corresponding milestones are depicted as a scheme in Fig. 3. The scheme also shows the roles of the different facilities in the different phases of repository implementation. The scheme clearly indicates that the activities in the different facilities do overlap with respect to time; e.g. activities for the pilot facility will start before the activities in the test facility have been finalised.

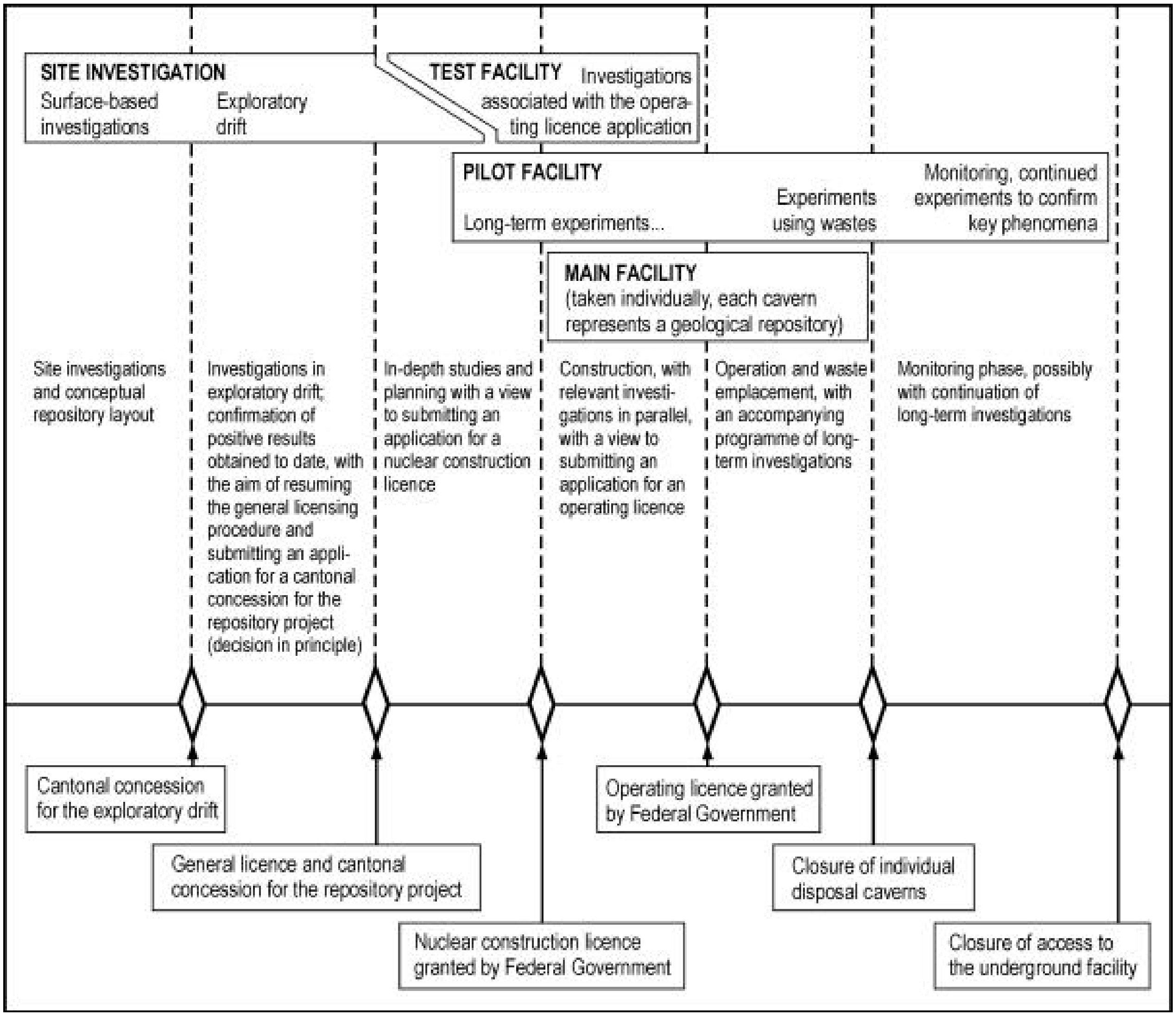

Fig. 3 Important milestones of the implementation scheme for the monitored long-term geological disposal of L/ILW in Switzerland

Monitoring and surveillance activities

For the phases depicted in Fig. 3, in-situ monitoring activities including some specific experiments are foreseen which take place in the different facilities. The in-situ activities are complemented by activities off-site, which may include work in generic rock laboratories, general laboratory work and studies and, in general, keeping an eye on the development of science and technology in the relevant areas. An overview of the activities, which have been proposed is summarised in Table I.

Table I. Key activities, their aims and the infrastructure used for the different phases of repository development

Aim	Site charac-terisation and infrastructure	Test facility	Pilot facility	Near-field and environmental monitoring	Investigations elsewhere
Confirmation of site suitability	properties and geometry of host rock, other				
Information for facility design	detailed geometry (incl. layout-determining features)	geomechanical aspects, construction aspects (incl. sealing)			material characterisation, emplacement technology, etc.
Confirmation of system suitability for operating licence		geological observations (incl. radionuclide (RN) migration, etc.)		base-line measurements for indicators (e.g. radioactivity)	radionuclide retention (sorption, ...)
Confirmation of system suitability for closure of main facility			monitoring of evolution in pilot cavern; monitoring geology (incl. RN migration); monitoring for early detection of deviations	monitoring of indicators	monitoring of progress in science & technology (incl. experience with other repository programmes)
Confirmation of system suitability for closure of all facilities			monitoring geology (incl. migration); monitoring for early detection of deviations	monitoring of indicators	monitoring of progress in science & technology (incl. experience with other repository programmes)
System evolution after closure of the facility				integration of monitoring of indicators into national surveillance network	

With the different surveillance and monitoring activities it is ensured that, for the different milestones regarding stepwise repository development, the necessary scientific information basis will be available. A summary of the activities foreseen for the key phenomena related to post-closure safety is given in Table II.

Table II. Summary of activities to confirm adequate understanding of key phenomena related to post-closure safety

Functional requirements	**Process**	**Approach / Infrastructure**	**Observed Parameters**
Immobilisation of radionuclides in the repository near field	near-field chemistry	monitoring of progress in science; specific studies if necessary	
		observations in pilot cavern ("black box experiment")	porewater composition
	sorption	laboratory experiments	various parameters
		observations in pilot cavern ("black box experiment")	radionuclides in porewater
		boreholes close to caverns	radionuclides in porewater
	evolution of cavern cross-section	measuring devices in specific cavern	deformations; stresses
Release of radionuclides from the near-field	water flow through disposal caverns	monitoring in boreholes and drifts	heads; water inflow; pore-water chemistry (indications of origin and age of water)
		boreholes close to caverns	heads
		observation in pilot cavern	resaturation
	sealing of disposal caverns	laboratory experiments (investigation of sealing materials)	various parameters
		observation in test / pilot cavern	various parameters
Radionuclide retention in the geosphere	water flow	monitoring in boreholes and drifts	heads; water inflow
	groundwater circulation	monitoring in boreholes and drifts	porewater chemistry (indications of origin and age of water)
	radionuclide migration	niche with short boreholes	tracer migration experiments
	sorption	laboratory experiments	different parameters
Long-term stability	seismicity	observation of earth-quakes	ground motions
	site stability	geodetic measurements	deformations
	general regional geological evolution	monitoring of progress in science; specific studies if necessary	

SUMMARY AND CONCLUSIONS

Monitoring should be considered as part of both the scientific work programme and the legal and societal framework within the stepwise implementation process of a geological disposal system for radioactive waste. Apart from any possible legal requirements for monitoring in the future, it is recognised that society demands the surveillance of a waste repository. Therefore, monitoring is a component of a wider repository surveillance strategy, consisting of a surveillance plan, a decision-making process (based on adequate criteria) and an appropriate scheme for actions and measures - where "proceed as foreseen towards repository closure" is the most probable case. The surveillance scheme, however, will not exempt the implementer from demonstrating the safety of the disposal system prior to waste emplacement, and monitoring actions or complementary measures must not compromise long-term safety.

Monitoring is related strongly to the different phases within a repository development programme and will therefore change from one phase to the next. The main aim of any monitoring programme related to post-closure safety is to confirm adequate understanding of the behaviour of safety-related system components: it thus provides part of the basis of the different performance assessments carried out to demonstrate compliance with the safety objectives.

Monitoring during the waste emplacement phase is also concerned with operational safety, ensuring radiation protection of the operating personnel and the general public as well as the protection of the environment. These monitoring activities will be very similar to those at nuclear facilities in operation today.

The implementation of a post-emplacement/pre-closure monitoring phase may turn out to be an important element for confidence building within the societal decision-making process aimed at repository closure.

For the post-closure phase, any monitoring will most probably be done from the surface, in order not to impair long-term safety, and will be continued as long as it is thought beneficial to society. This time period, however, will be short compared to the timescale over which radioactive waste (especially HLW and spent fuel) will remain hazardous. Any direct radiological evidence for the validation of predictive modelling results is very questionable; due to the high efficiency of the engineered (and natural) barrier system, the potential impact of activity released into the biosphere will be very small and will only occur a very long time after waste has been emplaced. Such measurements may, however, provide a good basis for public reassurance and may, indeed, be a societal requirement.

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