Expertengruppe Entsorgungskonzepte für radioaktive Abfälle (EKRA)
Expert Group on Disposal Concepts for Radioactive Waste

Disposal Concepts for Radioactive Waste

Final Report

Walter Wildi (Chairman)
Detlef Appel
Marcos Buser
François Dermange
Anne Eckhardt
Peter Hufschmied
Hans-Rudolf Keusen
Michael Aebersold (Secretary)

On behalf of the Federal Department for the Environment, Transport, Energy and Communication

31st January 2000

Report available from: Federal Office of Energy, CH-3003 Bern, Switzerland

Information: wildi@sc2a.unige.chmailto:wildi@sc2a.unige.ch, michael.aebersold@bfe.admin.ch

Contents

Overview

Mandate

In 1998, the "Energy Dialogue" working group set up by Federal Councillor Moritz Leuenberger was asked to consider fundamental aspects of nuclear waste management. The final report compiled by the chairman of this group at the end of 1998 contained recommendations for bridge-building between the opposing positions occupied by the operators of the nuclear power plants and environmental protection organisations. One of these recommendations was to look in more depth at the concept of "monitored retrievable long-term storage".

At the beginning of 1999, talks between the Federal Council, the siting Cantons (Cantons in which nuclear power plants are located and Canton Nidwalden), environmental organisations and the nuclear power plant operators on the lifetime of the existing power plants and solution of the waste management problem failed to reach a satisfactory outcome. In view of this, the Head of the Federal Department for the Environment, Transport, Energy and Communication (UVEK) decided to set up the Expert Group on Disposal Concepts for Radioactive Waste (EKRA) in June 1999.

EKRA then worked on providing the background for a comparison of different waste management concepts. The group developed the concept of monitored long-term geological disposal and compared this with geological disposal, interim storage and indefinite storage. The following aspects were at the forefront of these deliberations:

- active and passive safety
- monitoring and control
- retrievability of waste

This report presents the findings of EKRA.

Disposal concepts and waste management programmes

Ionising radiation causes damage to the human organism in the form of genetic effects and cancers. To prevent this, the human environment must be shielded effectively from the harmful effects of radioactive waste.

Almost all concepts for disposal of radioactive waste from the civilian use of nuclear energy were formulated at a relatively early stage, mainly in the nineteen fifties. The international community endorses the strategy of disposal of the waste in deep geological formations of the continental earth's crust; this is termed geological disposal. However, the arguments in favour of such disposal are not undisputed. Reservations are expressed mainly regarding whether or not the long-term safety of a repository can be ensured sufficiently given the means and methods available today. For this reason, over the last few years some countries have been studying, or even pursuing, strategies and concepts which, based on the principle of reversibility, foresee monitoring and control as well as facilitated retrieval of waste.

Today, Switzerland has two waste disposal programmes, namely for:

1. *Short-lived low- and intermediate-level waste (L/ILW)*
   Following a comprehensive site evaluation procedure, in 1993 the National Cooperative for the Disposal of Radioactive Waste (nagra) proposed Wellenberg as the site for a geological repository in a marl host rock. Based on the outcome of a public referendum in the siting Canton of Nidwalden, the repository project has been blocked since 1995.

2. *High-level and long-lived intermediate-level waste (HLW/TRU)*
   Nagra is working towards a feasibility demonstration for geological disposal in two potential host rocks, namely the crystalline basement and the Opalinus Clay; in Northern Switzerland the latter reaches a thickness of around 100 m.

Procedure followed by EKRA

As part of its mandate, EKRA investigated scientific and technical aspects of safe waste disposal - taking into consideration the requirement for sustainable development - as well as socio-political aspects. The most important values and objectives, ranked in order of significance are:

– the safety of man and his environment (top priority)
– freedom for all affected generations to make their own decisions, as well as fairness between different societal groups and between different generations (intra- and intergenerational equity)
– observing the 'producer pays' principle

– acceptance

Based on these criteria, EKRA formulated a set of conditions for safe disposal of radioactive waste in Switzerland. Conventional disposal concepts are described in this report and, building on this basis, the concept of monitored long-term geological disposal is developed.

The key technical and operational elements of this concept are a test facility, a main facility and a pilot facility. The aim of the test facility is to determine the suitability of the selected disposal site; it is operated prior to the emplacement of waste in the main facility. The main facility will receive the bulk of the waste. Up to the end of the observation phase, a small but representative component of the waste will be held in the pilot facility and will be monitored and controlled up to the time of final backfilling. A monitored long-term geological disposal facility can be closed within a short period of time, at which point it becomes a geological repository. From the point of view of long-term safety, the requirements placed on the site and the host rock are the same as for a geological repository.

Finally, the different concepts are compared and evaluated.

Conclusions

Evaluation of the different waste management concepts has led EKRA to reach the following conclusions:

1. *Interim storage facilities* do not meet the key requirement for long-term safety.
2. *Surface-based facilities and deep indefinite storage facilities* also fail to meet the criteria for long-term safety.
3. *Geological disposal* is the only method for disposing of radioactive waste which meets the long-term safety criterion (up to more than 100,000 years).
4. Social expectations in terms of waste disposal are oriented towards the principle of reversibility. EKRA has therefore developed the concept of *monitored long-term geological disposal*, which combines elements of disposal and reversibility.
5. With regard to safety and the procedures to be followed during the transition from monitored long-term geological disposal to geological disposal, there are still open questions which require to be answered.

6. Swiss disposal programmes:
   HLW/TRU: The host rock currently under investigation - the Opalinus Clay - is suitable in principle for both a geological repository and monitored long-term geological disposal.
   L/ILW: The above also holds true for the target host rock at Wellenberg; site characterisation should, however, be complemented by investigations in an exploratory drift.

Recommendations

Given the terms of its mandate, EKRA recommends the following programme of action:

a. Public debate on the issue of nuclear waste management is to be encouraged.

Nuclear energy legislation

b. Geological disposal for all waste types should be foreseen in the legislation. Project planners should be required to document, in ongoing projects, aspects of monitoring, control and facilitated waste retrieval as they apply in the concept of monitored long-term geological disposal.
c. Steps should be taken today to ensure that the waste management programme is financially independent of the nuclear power plant operators and the necessary institutional changes should be set in motion.

Wellenberg L/ILW project

d. Based on currently available information, the Wellenberg site fulfils the criteria for both geological disposal and monitored long-term geological disposal. The project should be pursued, whereby the modified disposal concept formulated by the GNW (Genossenschaft für nukleare Entsorgung Wellenberg) can serve as the starting-point. The possibilities for monitored long-term geological disposal should be investigated from the point of view of location and layout of a pilot facility. The first action at Wellenberg, however, is to take the necessary steps towards constructing an exploratory drift.

HLW/TRU programme

e. The host rock currently under investigation - Opalinus Clay - is suitable in principle for both geological disposal and monitored long-term geological disposal. Once the Entsorgungsnachweis (project demonstrating the feasibility of waste disposal) has been accepted, site characterisation should move forward and facility planning and site investigation should be initiated. International disposal options are in no way a replacement for solving the disposal problem within Switzerland itself.

Time schedule for realisation

f. A time schedule for realising both projects should be prepared and progress should be checked at regular intervals.

1. Introduction

Chapter 1 describes the background against which the Expert Group on Disposal Concepts for Radioactive Waste prepared the present report.

1.1 Nuclear waste management in Switzerland: background to the present report

Origin of waste

The first commercial nuclear reactor in Switzerland - Beznau I - started operating in 1969. Today there are five operational reactors (Figure 1). A large proportion of the radioactive waste for disposal comes from these plants. Waste also arises from the use of radioactive substances in the fields of medicine, industry and research.

NPP	Start of operation	Output in MW (as of 1.12.1998)
Beznau I	1969	365
Beznau II	1971	357
Mühleberg	1971	355
Gösgen	1978	970
Leibstadt	1984	1145

Figure 1: Swiss nuclear power plants (NPPs)

First research activities

The first efforts in the search for a repository for radioactive waste began at the end of the sixties.

"Project Gewähr 1985"

The National Cooperative for the Disposal of Radioactive Waste (nagra) was set up in 1972. In 1978, nagra presented the programme of investigations which would provide input to Project Gewähr 1985; the aim of this project was to demonstrate the feasibility of safe disposal of all types of waste in Switzerland. The results were presented to the Federal Council by nagra in 1985.

On 3rd June 1988, the Federal Council presented its evaluation of the results of Project Gewähr as follows (see also nagra 1997):

- All aspects of the feasibility of disposing of low- and intermediate-level waste (L/ILW) have been demonstrated.
- For high-level waste (HLW) and long-lived α-containing waste from reprocessing, the safety of disposal has been demonstrated but, as yet, no demonstration of siting feasibility exists.
- From an engineering point of view, there are no reservations regarding the construction of a HLW repository.

In addition to its investigations in the crystalline basement of Northern Switzerland, which were still continuing at the time, nagra was required by the Federal Council to initiate an investigation programme in sedimentary rock.

HLW programme

The investigation programme in the Opalinus Clay of Northern Switzerland began in 1991 (nagra 1994a). In particular, the combination of results from the exploratory borehole at Benken (Canton Zürich; 1999) and the 3D seismic campaign furnished encouraging results in terms of identifying a suitable site for a HLW repository.

L/ILW programme

Following the vote at the public referendum in Canton Nidwalden in 1995, the Federal Council suspended the application for a general licence for a L/ILW repository at Wellenberg in 1997. Since then, the repository project has been effectively blocked. To relieve this situation, the Federal Government and the Canton of Nidwalden set up two working groups, one to consider technical aspects of the project and the other socio-economic aspects. In their respective reports, both working groups outlined the framework for proceeding further with the project, as well as associated socio-economic considerations (TAG 1998, AGV 1998).

Energy Dialogue on waste management

In 1998, the Energy Dialogue working group was asked to address fundamental aspects of waste management with a view to providing input for formulation of new nuclear energy legislation (Kernenergiegesetz, KEG). The report compiled by the chairman of this group at the end of the year contained recommendations for bridge-building between the opposing positions held by the nuclear power plant operators and the environmental protection organisations (Ruh 1998).

Set-up of EKRA

EKRA was set up in the wake of the outcome of discussions between Federal Councillors Moritz Leuenberger and Pascal Couchepin and the siting Cantons, environmental organisations and NPP operators at the beginning of 1999.

1.2 EKRA's mandate

The Head of the Federal Department for the Environment, Transport, Energy and Communication (UVEK), Federal Councillor Moritz Leuenberger, gave the following mandate to EKRA:

EKRA is responsible for providing the background for comparison of different concepts for disposal of radioactive waste. In particular, the group should consider and compare geological disposal, monitored and retrievable long-term disposal and interim storage in the light of:

- active and passive safety
- monitoring and control
- retrievability of waste

The results, conclusions and recommendations of EKRA's deliberations should be compiled in a report which considers both technical and social issues and submitted to UVEK.

Based on this mandate, EKRA has developed the combined concept of monitored long-term geological disposal (KGL: note that here, and throughout the text, the German abbreviations have been kept for all disposal strategies; see Appendix 2). Using a set of evaluation criteria, this concept is compared with geological disposal, indefinite storage and interim storage. EKRA also suggests an action plan for future procedure in the field of radioactive waste management.

1.3 Working methods and composition of EKRA

Guidelines

EKRA proceeded on the assumption that the responsibility for defining the boundary conditions for radioactive waste disposal lies with society. Based on the action plan of the Federal Government (Aktionsplan 1997), EKRA focused on the principle of sustainability, according to which the radiological safety of present as well as future generations has priority over all other criteria.

Hearings

EKRA held a total of seven meetings between June and December 1999. At a series of hearings, the authorities (Federal Office of Energy BFE; Federal Nuclear Safety Inspectorate HSK), environmental organisations (Swiss Energy Foundation (SES), Greenpeace and a committee set up to allow the population of Nidwalden to express their views on nuclear facilities - MNA) and representatives of nagra and GNW (Genossenschaft für Nukleare Entsorgung Wellenberg) were invited to express their opinions.

Compiling the report

Based on the outcome of these hearings, and on discussions and literature studies, the text of the report was compiled chapter-wise by individual members of the group and was then edited for content and style. The participants at the hearings were given the opportunity to comment on a preliminary draft of the report and to suggest corrections or additions. However, EKRA alone bears ultimate responsibility for the content of the report.

Composition of EKRA

Chairman:
Prof. Walter Wildi, University of Geneva, geology

Members:
Dr. Detlef Appel, PanGeo Hanover, geology, radioactive waste
Marcos Buser, Buser & Finger Zürich, clean-up of contaminated sites, waste management concepts
Prof. François Dermange, University of Geneva, ethics
Dr. Anne Eckhardt, Basler & Hofmann Zürich, risk and safety
Dr. Peter Hufschmied, Emch + Berger Bern, hydrogeology, modelling
Dr. Hans-Rudolf Keusen, Geotest Zollikofen, tunnel construction, stability studies

Secretary:
Dr. Michael Aebersold, Federal Office of Energy

2. Evolution and Current Status of Waste Management Programmes

Chapter 2 highlights the developments which have led to waste management programmes as they are pursued today and describes starting-points for new strategies. Both the status in Switzerland and the international situation are presented.

2.1 The history of waste management programmes

Protection from ionising radiation

Ionising radiation causes damage to the human organism in the form of genetic effects and cancers. To prevent this, radioactive waste must be handled and managed under shielded conditions.

Management of radioactive waste

The problem of disposing of radioactive waste has existed since radioactive substances were first used in the fields of medicine, industry and research. From the start of military application of nuclear fission processes in the forties, and even more intensively since the peaceful use of nuclear energy from the nineteen fifties, the waste management issue has grown in importance on a worldwide scale.

Geological disposal (GEL)

The geological, technical and social problems associated with waste disposal were underestimated in the early days of the peaceful use of nuclear energy. As awareness of these problems grew, heated discussion began in many countries on the different disposal options, some of which are considered as being rather 'exotic' today (Figure 2). The main concern was high-level waste (HLW[1]), with the difference of opinion regarding disposal of low- and intermediate-level waste (LLW/ILW) being less intense.

Virtually all concepts for management of radioactive waste were formulated at a very early stage of use of nuclear fission, mostly in the nineteen fifties. Over the course of decades, scientific, technical, economic and ecological considerations, as well as political motives, have had the effect of restricting the number of options available.

---

[1] For the sake of simplification, HLW is assumed here to include spent fuel, although, from a legal point of view, spent fuel is not treated as waste in most countries. The terms "high-, intermediate- and low-level" are not based on any strict definition as they may vary depending on national disposal regulations.

For high-level and intermediate-level waste, and in some countries for low-level waste, the concept of disposal in mined facilities in deep geological formations of the continental earth's crust (termed geological disposal) began to be pursued by those responsible for waste management around the middle of the sixties.

Despite this move, doubts were expressed from the beginning about the concept of geological disposal. These related mainly to

– the discrepancy between the long time period for which the waste represents a hazard to man and his environment and the limited reliability of long-term predictions of the functioning of the barriers which are essential to the safety of repositories
– the lack of possibilities for access to the disposal facility in the event of failure
– the irreversibility of disposal.

Management concepts	Type, material	Comment	Author, year	Publication
HLW: immobilisation in clay	Particularly montmorillonite		Ginell et al., 1954	Nucleonics 12/12
HLW: vitrification and ceramics		Vitrification proposed since 1951	Rodger, 1954	Nucl. Engineering 50/5
HLW und L/ILW: disposal in near-surface strata	Dump or land-burial	As part of the nuclear fuel cycle concept	Goodman, 1949	Nucleonics 4/2
L/ILW (and HLW): dilution	Ventilation of gases and drainage of fluids		Beers, 1949 Scott, 1950	Nucleonics 4/4 Nucleonics 6/1
HLW and L/ILW: compaction	In boreholes or wells		Struxness et al. 1955	IAEA, Geneva, P/554
Liquid L/ILW: seepage	With seepage basin		Morton, 1952	NSA 6, 1212
Geological disposal	Sediments (clays, salt), then crystalline rocks, tuffs, etc.	Progressive development of concepts	Theis, 1955 Warde et al., 1955	IAEA, Geneva, P/564, J. of Metals, Oct. 55
L/ILW: sea dumping	Dumping	Regulated by the London Convention after 1972, moratorium since 1985. To be prohibited in terms of the London Convention	Claus, 1955	IAEA, Geneva, P/848
HLW: subseabed disposal	Disposal in unconsolidated, undisturbed marine sediments	Pursued from 1977 as the "sub- seabed" project	Evans, 1952	NSA 8, 1954: 4929
HLW: disposal in subduction zones	Submarine repository in subducting oceanic plate	Risk of volcanism	Bostrom et al., 1970	Nature 228
HLW: disposal in fault zones	Deep sea trenches		Bogorov et al., 1958	IAEA, Geneva, P/2058
HLW: disposal in ice	Antarctic repository	Meltdown of hot waste (ice melting)	Philbert, 1959	Atomkern-Energie, 4/3
HLW: meltdown in the deep underground environment	Deep underground melting	Liquid HLW in an atomically generated cavern	Cohn et al., 1972	Nuclear Technol., April 1972
"Disposal" in space			Hollocher, 1975	MIT Press
Transmutation			Cecille et al., 1977 Hage W., 1978	IAEA, Vienna, 36/366 EUR-5897

Figure 2: Waste management concepts proposed since 1949 (completed after Buser 1998)

Alternative disposal concepts

As early as the beginning of the seventies, proposals for alternative concepts were starting to be discussed (IAEA 1971, Buser & Wildi 1981). Considerations such as the need for monitoring and the possibility of retrieving waste from a disposal facility led to concepts which placed more emphasis on elements of social control (Hammond 1979, Roseboom 1983). Towards the end of the eighties, these concepts were taken up by movements with more mystic beliefs; this trend culminated in a concept calling for indefinite supervision of radioactive waste (nuclear guardianship; Kreuzer 1992, Buser 1997, 1998). There was then a move on the part of environmental organisations to endorse new concepts in which the emphasis was on ethically motivated principles (Bär 1997, SES/Greenpeace 1998).

2.2 Waste management programmes abroad

Geological disposal of HLW

While most countries foresee geological disposal for civilian HLW and ILW containing long-lived nuclides, handling of LLW and ILW differs depending on their hazard potential (radiation, heat production, component of long-lived radionuclides) and the national safety standards which apply in each case.

Prohibition of dumping

Sea disposal of waste no longer comes under discussion. Since the 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (the London Convention), there has been a moratorium on sea dumping. An additional protocol to the Convention will, in principle, prohibit sea disposal of solid and liquid radioactive wastes in the future. For wastes containing predominantly short-lived nuclides (in some countries: half-life < 30 years), the most cost-effective method of disposal is in technically more or less sophisticated near-surface facilities.

Geological disposal of LLW and ILW

In Cuba, Finland, Norway, Sweden, Switzerland and the Czech Republic (Han et al. 1997), repositories in easily accessible tunnels or caverns several tens to hundreds of metres beneath the earth's surface are being planned, or are already in operation, for LLW and ILW with a high concentration of short-lived nuclides. Germany, Great Britain and Rumania plan geological disposal for these waste types in deep engineered facilities accessible only via shafts; this is the exception rather than the rule.

Arguments in favour of geological disposal focus mainly on safety: the distance between the waste and the biosphere, the slow flow rate of the transport medium groundwater, the retention capacity of the geosphere for any radionuclides released from the repository and the inherent passive safety resulting from the system of multiple engineered and natural barriers. The ethical justification for geological disposal is the belief that the burden of dealing with the waste should not be passed on to future generations who did not benefit from the use of nuclear energy (NEA 1995).

Alternative disposal concepts

In the last ten to fifteen years, however, increasing doubt has been expressed in many quarters regarding these arguments, resulting in social and political opposition to concrete disposal projects.

Variants on the conventional approach to disposal have thus been proposed or completely new management strategies formulated. This applies particularly to high-level waste and long-lived intermediate-level waste. Options which are being discussed internationally today include in particular

- Disposal with a preceding demonstration or test phase in either the repository itself or in an underground laboratory in the area of the planned repository
- Disposal with a long period of waste retrievability (and monitoring), either limited or unlimited in time
- Long-term storage (either limited or unlimited in time) of the waste (with monitoring) in a surface or underground facility
- A combination of several options

Whether or not any of these options are investigated or pursued in individual countries depends on the motives for changes in strategy and on the specific boundary conditions in each case, particularly the size and profile of the nuclear energy programme.[2]

[2] With or without breeder technology, reprocessing.

	France	USA	Netherlands	Sweden
Primary objectives	Improving safety, improving demonstrability, sustainability, gaining acceptance	Improving safety, improving demonstrability, gaining acceptance	Improving safety, improving demonstrability, sustainability, gaining acceptance	Demonstration phase: improving safety; GEL-R[3] still unclear (gaining acceptance?)
Technical objectives	Long-term storage, GEL-R: Bridging time gap till separation of long-lived radionuclides/transmutation, reversibility, monitoring of waste; Rock laboratory: building up experience, decreasing system and demonstration uncertainties, investigation of retrievability	Checking disposal system behaviour, verifying models with safety analyses, reacting to unforeseen events	Bridging time gap till separation of long-lived radionuclides/transmutation, reversibility, monitoring of waste, maintaining reprocessing option	Demonstration phase: demonstration of safe functioning of disposal system, gathering experience; GEL-R: still unclear
Time period for implementation	Long-term storage: not defined; GEL-R: not defined (approx. 300 years)	50 years direct access to waste, retrievability of waste for 100 years from beginning of emplacement (extendable to 300 years)	Long-term storage: not yet defined (up to several hundred years); GEL-R: up to 200 years (final backfilling after up to 600 years)	Demonstration phase: at least 5 years; GEL-R: not yet decided
Nature of implementation	Evaluation of different options by 2006: surface/underground long-term storage, GEL, different phases of GEL-R; rock laboratory: investigations (understanding of disposal system, demonstration methodology)	Retrievable storage of containers in tunnels, monitoring, investigations (effects of heat emission on host rock, container corrosion)	Evaluation of different concepts by 2000 with the phases: long-term surface storage (100 to 300 years), GEL-R (up to 200 years) and final GEL backfilling	Demonstration phase: part of the foreseen inventory will be stored retrievably in part of the repository GEL-R: not yet decided
Affected waste	Long-term storage and GEL-R: mainly spent fuel, HLW and long-lived ILW with potential for re-use; GEL: waste with no potential for re-use	Spent fuel, other civilian HLW	All waste (possibly only HLW and long-lived ILW with re-use potential)	Spent fuel
Sites (host rock)	Rock laboratory/ GEL-R: site "L'Est" (clay) and not yet named (granite)	Yucca Mountain (tuff)	Not yet named (rock salt, possibly clay)	Not yet named. Selection procedure underway (crystalline)
Implementation status	Concept development, comparative safety studies	Detailed planning, site suitability results around 2001	Concept development, comparative safety studies	Demonstration phase: detailed planning; GEL-R: concept development
Nuclear energy programme (1998/1999)	62 NPPs (two fast breeders), no plans to phase out nuclear energy	104 NPPs, no plans to phase out nuclear energy	One NPP, phasing out of nuclear energy planned for 2004	12 NPPs, phasing out of nuclear energy planned for 2010

Figure 3: Waste management strategies in France, the USA, the Netherlands and Sweden

[3] GEL-R: Disposal with a long period (either initially restricted in time or unrestricted) of retrievability (and monitoring) of the waste.

Examples from France, the USA, the Netherlands and Sweden

By way of an example, Figure 3 shows the planned or already implemented disposal concepts for civilian waste in France, the USA, the Netherlands and Sweden. The information was taken from ANDRA (1997), CNE (1998, 1999), CRWMS (1998), Dodd et al. (1998), EIA (1999), IWM (1999), NEA (1997a, 1997b, 1998), NL (1993), OCRWM (1998), Richardson (1999), Selling et al. (1998), SKB (1999) and SKI (1999). It relates mainly to aspects which are of significance for discussion of conventional disposal strategies or alternatives thereto. It should be noted that certain options can relate to different waste types.

The selection of France, the USA, the Netherlands and Sweden covers a wide range of already largely obligatory alternatives to conventional disposal. The nuclear energy programmes in these countries are also very different. The following points should be borne in mind regarding the level of maturity of the four national strategies:

The French and Dutch waste management programmes are still in a developmental stage. The given options are presently being investigated with a view to deciding on a final concept.

The basic strategy in the USA was established by legislation in 1982 (Nuclear Waste Policy Act) and has only been modified since then.

In Sweden there are as yet no binding regulations regarding a phase of retrievability, but retrieval techniques are the subject of intensive study (SKB 1999).

Reasons for alternatives to disposal

The motives and driving forces which led to the concepts which were initially pursued being abandoned varied from country to country. In France and the USA, rethinking led to strong opposition being developed to individual disposal projects on a local and regional scale - this was exacerbated by inadequacies in the methods applied for selection of repository sites. The new approach was aimed at improving public acceptance. The same is also true for Sweden and the Netherlands, although no major acceptance problems have been encountered in these countries to date. In France and the Netherlands, since 1991 and 1993 respectively, reversibility of every type of waste disposal has been the primary political (and in France also legal) waste management requirement.

The primary and technical objectives of the four waste management strategies presented in Figure 3 also play an important role in discussions outside the countries in question.

Improving safety and demonstrability

To enhance the safety of existing or planned disposal facilities, and to improve the reliability of demonstrations of suitability, a (short) test phase and/or a defined (longer) phase with easy retrievability of the waste will be introduced in the countries under consideration, as well as in some other countries (e.g. Great Britain). The aim during such phases is to demonstrate the technical feasibility of disposal, to observe the behaviour of the disposal system and to reduce the uncertainties (in knowledge and prediction) associated with disposal. At the same time, an underground laboratory can be used to obtain host rock- and site-specific information.

The nature and scope of monitoring measures and investigations to be carried out in order to achieve phase-specific objectives are presently being discussed or planned. The appropriateness of a phase with facilitated waste retrieval, aimed at providing long-term information which will reduce uncertainty, is however disputed, particularly when considering the requirement for long-term safety.

Wide-ranging investigations are being carried out in France and the Netherlands. However, the situation is different to the current discussion in Switzerland, in that complementing or replacing natural and engineered barriers with monitoring and repair measures is not the key issue.

Reducing the hazard potential of the waste

The main consideration is bridging the time gap until advanced technologies become available for reducing the hazard potential of the waste or until certain waste types can be handled by separating out long-lived nuclides and transmuting these to short-lived nuclides. In both countries (as well as in the USA; DOE 1999), the potential for developing such technologies is presently being evaluated. This trend is dictated more by energy and research interests than by waste management interests. Actually realising such strategies on a national scale is being considered only in France and, even in this case, there are doubts about whether such procedures would be justified in terms of safety and economics.

In Sweden (and other countries), strategies which are aimed solely at bridging the time period until new technologies are available are unacceptable. This is justified mainly by the small scale of the nuclear programme, the uncertainty of future technological evolution and costs and environmental impact of the necessary facilities. This is even more true in view of the fact that disposal is still necessary in case of separation and transmutation (NEA 1999).

Gaining acceptance

In all the countries looked at, obtaining acceptance for waste disposal strategies plays a very important role, although it remains to be seen whether or not the chosen procedures will actually have the effect of promoting acceptance. The feeling of the Dutch public at least seems to be that the only purpose of pursuing alternative strategies would be to lay to rest the fears of the population (Damveld & Van den Berg 1999a).

In the USA, opposition to concentration on Yucca Mountain (Nevada) as the sole disposal site for civilian HLW has not led to any significant modification of the disposal concept, although alternatives - particularly long-term storage - have been discussed (Gervers 1993). Efforts have concentrated much more on informing and involving the public in decision-making processes with a view to improving acceptance. However, this has not had the effect of reducing opposition to the project - for example in the state of Nevada.

Conclusions

In conclusion, it can be stated that the objectives of sustainability and acceptance do not indicate a clear path towards one specific disposal concept; neither are they directly associated with safety. Depending on the procedure which is derived from it, the ethically motivated requirement to "maintain the freedom of decision of future generations" can actually lead to contradictory conclusions.

Overview

In most countries, wastes containing primarily short-lived nuclides are disposed of in facilities at or near the earth's surface, generally without any intention of retrieval. For high-level and long-lived intermediate-level waste, alternatives to the previously preferred option of geological disposal have been discussed for several years.

The discussion is intensifying on a worldwide scale. This trend is due not so much to the fact that alternative waste management concepts offer advantages in terms of safety for the responsible organisations, but rather that, given the wide opposition to geological disposal in general and to concrete repository projects in particular, a number of countries have felt the need to react to the fears being expressed. In France and the Netherlands, respectively, the legally and politically binding principle of reversibility has meant that the concept of conventional disposal has had to be abandoned.

All the countries considered are either investigating or following up the possibility of extending the conventional disposal concept to include a preceding demonstration or test phase, as well as a precisely defined phase with facilitated waste retrieval. This approach is also being considered in some other countries, particularly for HLW and spent fuel.

In France and the Netherlands, the entire strategy to date for management of high-level and intermediate-level waste (France) and probably all waste types (the Netherlands) is in a review phase. The alternatives "disposal with long-term retrievability of the waste" and "long-term storage of waste" are intended mainly to bridge the gap until such time as technologies for reducing the long-term hazard potential of the waste or a definitive solution can be realised. However, the question whether technologies of this kind can in fact be developed remains open at present. Neither a concrete time perspective nor safety advantages can be seen for such solutions.

2.3 The Swiss waste management programme

2.3.1 Legal framework

Handling radioactive wastes

In Switzerland, dealings with radioactive waste are regulated by the Radiological Protection Law of 22nd March 1991 and the Radiological Protection Ordinance of 22nd June 1994. In particular, the Radiological Protection Law states that radioactive waste arising in Switzerland shall, in principle, be disposed of domestically. The Federal Council is responsible for defining the conditions under which, by way of an exception, an export licence for such waste may be granted (Art. 25, para. 3).

Exporting waste

Nuclear legislation

The Atomic Law of 23rd December 1959 forms the legal basis on which management of radioactive waste arising from the peaceful use of nuclear energy is founded. According to the Law, facilities for storing waste require to be licensed and supervised by the Federal Government. The Law is supplemented by the Federal Government Act on the Atomic Law of 6th October 1978, which embodies the principle that the producers of radioactive waste are responsible, at their own expense, for its safe disposal. The Federal Government retains the right, if necessary, to dispose of the waste itself at the expense of the producers (Art. 10, para. 1).

The Swiss Federal Nuclear Safety Inspectorate (HSK) is the supervisory authority. In its Guideline HSK-R-21, HSK defines the protection objectives for disposal of radioactive waste. Guideline HSK-R-14 regulates the conditioning and interim storage of radioactive waste.

2.3.2 The L/ILW and HLW/TRU programmes

Today, Switzerland has two disposal programmes:

L/ILW programme at Wellenberg

1. *Short-lived low- and intermediate-level waste (L/ILW)*
   Following a lengthy evaluation procedure, in 1993 nagra proposed Wellenberg as the site for a L/ILW repository. In 1994, the implementing body GNW (Genossenschaft für nukleare Entsorgung Wellenberg) was set up and an application for a general licence submitted. On 25th June 1995, in a close result, the electorate of Canton Nidwalden voted against both the recommendations of the Cantonal Government of Nidwalden on the application for the general licence and the granting of a concession for use of the underground. On 4th June 1997, UVEK suspended the general licence application.

Based on discussions held between 1995 and 1998, GNW has now proposed a modified disposal concept for Wellenberg (nagra 1998). This foresees a period of monitored disposal in open, non-backfilled caverns. GNW has also expressed its willingness to proceed in a stepwise manner and to apply, in the first stage, for only a part-concession for construction of an exploratory drift.

Since the outcome of the referendum in Nidwalden, the L/ILW disposal programme has been blocked. To be able to continue with the project, GNW needs both a political decision and a cantonal permit to allow the suitability of the proposed host rock to be investigated using an exploratory drift.

2. *High-level and long-lived intermediate-level waste (HLW/TRU)*

HLW/TRU programme

For HLW/TRU, nagra is seeking to demonstrate the feasibility of geological disposal in two potential host rocks:

Crystalline basement of Northern Switzerland

As part of the "Kristallin" project, nagra investigated disposal options in the crystalline basement of Northern Switzerland. The general suitability of this rock type was demonstrated in Project Gewähr 1985. However, from a geological point of view, the crystalline basement of Northern Switzerland is difficult to explore. A further drilling application was suspended following the lack of promising results from seismic measurements aimed at identifying a suitable body of rock. The crystalline option is considered today to be a reserve option.

Sediments (Opalinus Clay) of Northern Switzerland

In 1988, the Federal Council requested that the investigation programme be extended to include sedimentary rocks. In a first stage, nagra considered two formations, namely the Lower Freshwater Molasse and the Opalinus Clay (nagra 1988). The latter option was finally selected on the basis of its greater homogeneity and lower hydraulic permeability, compared with the Lower Freshwater Molasse (nagra 1994a). Investigations in sediments in the northern part of Canton Zürich began in 1994 and, since 1997, nagra has been carrying out studies in the area known as the Zürcher Weinland. Seismic measurements and the results from the Benken borehole (drilled in 1998/99) confirmed the positive expectations (nagra 1999). The 'Entsorgungsnachweis' (project demonstrating the feasibility of disposal) will therefore focus on the Opalinus Clay, which is around 100 m thick in the area of interest.

Rock laboratories

Nagra also carries out scientific and technical studies in two underground rock laboratories:

In the Mont Terri Rock Laboratory (Canton Jura), the properties of the Opalinus Clay as a potential repository host rock are being investigated. Several foreign organisations, for example from Germany, Japan, France and Spain, are involved in the laboratory programme.

At Nagra's Grimsel Test Site, a range of experiments with wide international participation are being carried out in crystalline rock.

3. Social Expectations Regarding Radioactive Waste Management and Consequences Arising Therefrom

Chapter 3 analyses and evaluates social expectations regarding radioactive waste management. Further developments of the Swiss concept have to take these expectations into consideration. The subject-matter of this chapter is justified by the fact that, up till now, too little attention has been paid to these expectations.

3.1 Social decisions and expert judgement

Involvement of society

For a long time it was assumed that management of radioactive waste was a matter purely for experts. In recent years, however, there has been an increasing call for society as a whole to be involved in the decision-making process. Discussion of key issues is thereby enriched, but it also becomes more complex. The question is how to reconcile different forms of knowledge, levels of rationality and claims of truth and, at the same time, carry on a pluralistic and democratic discussion on the topic of radioactive waste management.

Ethics as a guide to decision-making

In this sense, ethics is to be understood not only as one more form of knowledge, which can itself be divided into different philosophical and anthropological movements, but much more as actually embodying the attempt to find a solution to the waste management issue. This solution not only has to take into account the diversity of ideals and world-views that abound in our society, but also has to provide a response to the challenge of how we deal with the radioactive waste generated by us which will remain relevant and convincing for thousands of years.

Pluralism as a value

a. *Democratic decision-making in a pluralistic society*

One important criterion to be considered when seeking a solution to the waste management problem is the pluralistic and democratic nature of society. This means:

There is no such thing as an inroad to ethics which can be detached from public discussion. Whoever claims, in the name of science, economics or some particular philosophical or transcendental concept, to have privileged access to the truth can rightly be countered with a whole series of different opinions which are equally justified a priori.

Society abounds with a diversity of world-views and opinions regarding mankind and his destiny and these are often incompatible with one another. Even so, there is no compulsion towards either subjectivism (ethics is a private matter for each individual) or relativism (all opinions are equal).

Common values

What the waste disposal issue really requires is democratic decisions. Democracy is based on common values, such as equal rights and equal protection of all citizens by the state, which are embodied in the constitution. It is also founded largely on accepted rules and procedures. Sharing of values, procedures and rules forms the basis for resolving social conflicts.

b. *A diversity of opinion*

Fundamental questions

The management of radioactive waste is the subject of intense international discussion. It seems that the issues involved are particularly effective in bringing to the fore the differences of opinion which prevail in democratic societies. The result is that all sides strive to provide ethical arguments to support their own particular goals.

Technology and society

Two opposing viewpoints are considered by way of an example. For one side, the waste management problem is purely a technical issue which should be solved with scientific objectivity. The critical view of society is not sought in this case. For the other side, the problem is inextricably bound up with the question whether there should be continued use of nuclear energy. Solving the waste management issue then means accepting and legitimising the use of nuclear energy at the same time.

Freedom of decision
- but how?

There is general agreement on the basic principle that the freedom of action of future generations to decide on waste management questions should be maintained. However, there is disagreement as to how this principle should be interpreted. Is it best served by sealing a disposal facility as quickly as possible, leaving our descendants with no burden to monitor or maintain the facility? Or does it mean that the evolution of the disposal system should be continuously monitored and that there should be access to the waste at any time?

On another level, the representatives of an ethical belief which relates to some kind of good (from the happiness of mankind to social prosperity) are opposed to those who stand by the theory of fairness or justice (comment 1[4]).

Ethical theories

There is a link, be it conscious or subconscious, between such ethical standpoints and the arguments which shape the current discussions. Of particular importance here are the principles of teleology (interpretation of things in terms of purpose), the different variants of utilitarianism, the ethics of responsibility (Jonas 1979), communitarianism and Neo-Aristotelism (Walzer 1983, Taylor 1992), as well as deontology.

Optimise benefits, observe rights

The utilitarian and deontological or contractual approaches are often contrasted (comment 2). The objective of the utilitarian approach is generally to achieve the maximum possible economic benefit for the maximum number of people; risks are acceptable if they lead to considerable economic advantage. In the deontological approach, observing the individual moral rights as they are recognised in a democracy stands in the foreground.

c. The value of expert opinion

Tasks of society

As previously mentioned, a wealth of visions and ideas exist in a democratic society. This diversity is *a fact*, but it can also be seen as a common *good*. It cannot be the task of the experts to give precedence to one of the competing concepts. It is much more a responsibility for democracy, using its institutions, to determine what is desirable from a social point of view.

Tasks of the experts

Experts should, however, be responsible for determining the underlying values which form the prerequisite for the democratic power-play in a society. Objectives or values must be arranged in some kind of hierarchy which ensures the continuance of democratic power-play, while safeguarding the principles of plurality and mutual respect. This approach is presented in the following sections.

---

4 Comments relating to chapter 3 can be found at the end of the bibliography.

3.2 Evaluation criteria

a. Safety of man and the environment

Safety has priority

The paramount objective and value of every radioactive waste management concept has to be the safety of man and his environment. This fundamental principle is not in dispute. Safety is necessary for an individual to be able to act, make decisions and make use of his freedom.

b. Fairness

Equal rights for all

Once a sufficient level of safety has been assured, then fairness takes on a central role. Fairness is both the pivot and the crux of every democratic society. All citizens have the same rights and also the right to be treated equally. For example, no one should be placed at a disadvantage because of his opinions or affiliation to a particular social group. This principle should also apply over time; no one should be discriminated against on the basis of belonging to a different generation (Parfit 1983). As long as radioactive waste represents a risk to man, future generations have the right to the same level of safety as people living today.

Rejection of discounting

This means that the attempt on the part of some utilitarians to discount future risks in the cost-benefit analysis has to be rejected. Morally speaking, there is no difference between current and future risk. Theories which, for example, attempt to discount effects on human health in twenty years to the extent that they are equivalent to only one-tenth of present-day effects in cost-benefit considerations are not acceptable.

Differentiation according to time period

Disposal of radioactive waste affects future generations over time periods which, in the case of HLW, are in excess of 100,000 years. However, typical social timescales never really extend beyond 1000 years. The timescales involved in radioactive waste disposal are thus so long that they exceed the possibilities of our society in terms of passing on technical know-how and stability of political and social institutions.

When considering concepts for radioactive waste management, a distinction has to be drawn between two different time periods, namely that which lies within the grasp of the present society (comment 3) and that during which the safety of man and his environment has to be ensured without any human intervention (comment 4).

In the following, we concentrate on the time period which lies within the grasp of present-day society. However, it should not be forgotten that the significantly longer time period which follows this is of greater significance overall in terms of safety.

c. *Individual and social acceptance*

Acceptance and compensation

The criteria of safety and fairness demand that risk should be distributed evenly among all people. However, such a fair distribution is impossible as a rule. Burdening someone with a risk therefore always assumes direct or indirect acceptance by the individual and, if necessary, appropriate compensation.

A waste management concept would therefore be defendable only if it left open to every generation the possibility of either shaping it or rejecting as an expression of the right of self-determination as part of democratic decision-making.

Social acceptance

The requirement for social acceptance is somewhat weaker. At the time of its construction and operation, a waste disposal facility has to be accepted by the majority of the Swiss people, particularly in the siting region. The facility should be designed in such a way that there will also be a good chance of it being acceptable to future generations.

Compared with safety and fairness, the criterion of acceptance is of secondary importance because it clearly favours the present and perhaps some immediately following generations over later ones. In the sense that we feel entitled today to make a decision which may involve irreversible consequences or considerable burdens for future generations, we are contravening the principle of fair treatment.

Weighing up different values

One example of this is a geological disposal concept where the repository will remain open for a period of 100 years. A higher level of social acceptance is to be expected for this variant than for a geological repository which is sealed immediately after the operating period. The freedom of future generations in terms of being able to retrieve the waste is also greater in the former case. On the other hand, in the case of a facility which initially remains open for 100 years, there is the possibility, on the long term, of some degree of safety being sacrificed. An increased hazard for persons working in the facility would also be inevitable. Future generations would also be burdened with the monitoring, control, maintenance, security and sealing of the facility.

3.3 Fundamental principles of disposal concepts

a. *Safety is of paramount importance*

Integrated consideration of cost and benefit

If one strives, in a utilitarian sense, to maximise quantifiable benefit, then an integrated cost-benefit analysis would have to be performed for every disposal concept. In this case, if discounting is left aside, then even a small but temporally almost unrestricted risk can have a strong influence on the cost-benefit ratio. Proponents of utilitarianism therefore prefer to find as rapid and efficient solution as possible to the disposal issue, which would restrict future risk to a minimum. The freedom of future generations would be ensured in this case as they would not be saddled with any burdens.

Already today, efforts should be made to ensure the maximum possible safety for man and his environment during the whole 'lifetime' of the waste, in order to place as small a burden as possible on future generations.

Need for control

This approach is supported by many technical experts. Counter-arguments are brought, inter alia, by environmental organisations and contractualists. Accusations are made that scientific solutions would be influenced by short-term economic considerations, or that society should be prevented from accepting responsibility for the risks it has created, or that potential problems in the future would not be handled with the necessary conscientiousness.

One significant argument applies to the safety of man and his environment. According to this argument, the uncertainties associated with prediction can lead, particularly over long time periods, to unacceptable risks. For this reason, monitoring and control measures are necessary (comment 5). Relevant experience should also be gathered for the purpose of verifying models over longer time periods.

b. *Technical control and democratic instances are inseparable*

Controlling instances

Technical control assumes the pre-existence of social institutions. In the case of radioactive waste management, the question arises as to who has the power to assume such control. How can it be ensured that the responsible instances will carry out the tasks assigned to them reliably, indefinitely, independently and with democratic authorisation? The answer to these questions is determined less by technical constraints than by what is seen as socially desirable.

Demands on the controlling instances

As long as a radioactive waste disposal facility requires to be controlled, there has to be some kind of institution which fulfils the above requirements and is socially acceptable. Investigations have shown that a risk which cannot be controlled by the individual is nevertheless acceptable if it is controlled by an institution which is widely regarded to be competent and is trusted by society (Slovic 1991). It also seems to be important that such an institution should be largely independent of the nuclear energy producers and the government at the time (Damveld & Van den Berg 1999b).

c. Innovation as an option

Making use of innovations

What is considered today to be an optimum solution is influenced strongly by the state of technological development and knowledge. Both of these will progress further in the future and will probably open up new solutions to the radioactive waste disposal problem.

Avoid permanent obligations

From this point of view, it would seem to be advantageous for future generations to have the opportunity, over longer time periods, to handle emplaced waste differently, to re-dispose of it or - in the case of HLW - to re-use it. They should also have the freedom to monitor the behaviour of the disposal system. However, this freedom is restricted if the repository burdens future generations with long-term responsibilities or obligations over which they have no power of decision (Shrader-Frechette 1993, MacLean 1986). In this case a social decision is required.

d. Determining an acceptable level of safety is a matter for society

The freedom of society to decide also applies in the case of determining the required level of safety.

What level of risk is acceptable?

The level of risk which is acceptable is influenced by a range of social boundary conditions, including the state of development of science and technology. However, the acceptable level of safety must ultimately be specified in a democratic decision. For ethical reasons, it is also necessary for future generations to have some freedom of decision to allow them to specify what they believe to be an acceptable risk.

Risk is generally considered to be a function of likelihood of occurrence of an event and the extent of damage arising. When making recommendations as to what is an acceptable risk level, many experts still explicitly assume that natural risk or risk which has been accepted to date represents an acceptable level. In contrast with this, the contractualist approach stresses that even an existing, accepted risk level always has to be interpreted in the light of the current state of knowledge and social expectations. One example is the ever-recurring debate over acceptable radiation doses.

Naturalistic fallacy

From a philosophical viewpoint, trying to derive an acceptable risk from a natural one is an example of the so-called 'naturalistic fallacy' (Moore 1951). The starting-point and the desired end-point should never be confused. In addition, the safety of radioactive waste disposal is not only a question of absolute risk (risk magnitude), but also of the existing possibilities for reducing risk.

The safety of radioactive waste disposal should be checked by suitable measures before the facility is definitively closed and sealed (repository).

Control is comprised of both social and technical components. It has to be exercised by a reliable, long-term, independent and democratically legitimated controlling instance. The principle of reversibility has to be taken into consideration in planning a disposal facility, i.e. each generation should, in principle, have the possibility to make use of new knowledge regarding disposal and disposal requirements.

Reversibility

These fundamental principles can be brought together in the concept of reversibility. Reversibility is a key element of sustainable development as it takes into account the protection of man and his environment, fairness, economic progress and social cohesion.

3.4 The 'producer pays' principle

Costs of waste management

Future generations should be burdened as little as possible by waste disposal. This is justified not only from the point of view of utilitarian considerations but also on the grounds of fairness. There is the potential for a considerable imbalance of the cost- benefit ratio between present and future generations. It would be unfair if those generations benefiting from nuclear energy were to pass on the external and resulting costs of this benefit to later generations.

Economic principles of waste management

From an economic standpoint, and with a view to careful use of resources, the cost of constructing, operating, monitoring and controlling the disposal facility should be kept as low as possible, while still maintaining the required level of safety. In terms of fairness and freedom for future generations, particular attention has to be paid to resulting costs.

'Producer pays' principle

The producer pays principle also has to be taken into consideration. The content of this principle is basically to the effect that the producer (polluter) must bear the cost of any measures taken to put the environment in an acceptable state (comment 6). However, it is often the case that the producer is required to compensate victims or make good environmental damage only when an accident occurs or when some legally specified boundary value is exceeded. He is not held responsible for the residual risk or for the often chronic environmental damage which is below the boundary values. However, compensation, as it is increasingly finding application in ecological policy, could be relevant in this case (Barde 1991).

a. *Compensation*

It is essential for radioactive waste disposal that cost and benefit be fairly distributed - both in spatial terms and over longer time periods. Increased risks in the vicinity of the disposal facility location must be defensible based on appropriate compensation or from the viewpoint of solidarity of society as a whole. Compensation is particularly important in cases where the permission of those persons affected has not been obtained and a fair distribution of cost and benefit cannot be achieved. Compensation has to be agreed with the persons affected, whereby future generations have to be taken into account (see also AGV 1998).

b. *Costs of monitoring and control*

The costs of monitoring and controlling a disposal facility, and for the controlling instances, must also be taken over by the producer during the necessary period of observation.

c. *Costs of retrieval*

Facilitated retrievability of the waste is part of the requirement for reversibility and necessitates both technical and financial means. If retrieval is effected for safety reasons, then the case is one of liability which has to be regulated by law. If retrieval is implemented for other reasons, then no reserves require to be put aside by the generations who are benefiting from the use of nuclear energy.

d. *New waste treatment methods*

No financial reserves require to be put aside to cover the cost of potential new methods for treating radioactive waste, as long as the safety of future generations is not unacceptably compromised by the omissions of the benefiting generations.

4. Basic Elements of the Swiss Waste Management Concept

Chapter 4 presents the guidelines and boundary conditions for waste management, taking social expectations into consideration.

Figure 4 shows the social and technical guidelines and boundary conditions for waste management.

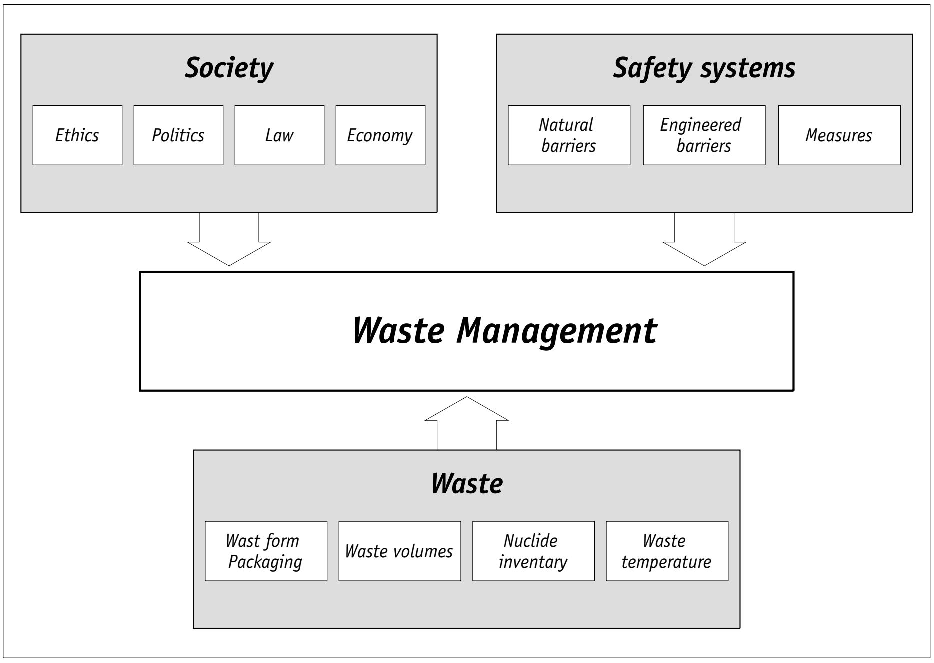

Figure 4: Guidelines and boundary conditions for waste management

4.1 Waste inventory

Waste types

For the purpose of allocation to the individual repository types, the different waste types are characterised and assigned to so-called waste categories. Based on their origin, the following five waste types are distinguished in Switzerland today (nagra 1994b):

- operational waste
- reactor waste
- decommissioning waste
- reprocessing waste
- waste from medicine, industry and research (MIR waste)

If full reprocessing is abandoned, spent uranium and MOX fuel elements[5] will have to be conditioned and disposed of as HLW.

Waste categories

Based on toxicity, the component of long-lived nuclides and the results of long-term safety analyses, these waste types are classified in Switzerland into three categories, namely low- and intermediate-level waste (L/ILW), long-lived intermediate-level waste (TRU) and high-level waste (HLW). To date, only a proportion of operational waste and MIR waste has arisen and as yet no decommissioning waste, meaning that the description of the waste types is based on model values. It should also be noted that abandoning reprocessing will result in direct disposal of fuel elements and an associated change in waste volumes. Figure 5 gives an overview of the expected volumes for the different waste types.

Waste type	**L/ILW**	**TRU**	**HLW**
Operational waste NPP	9,200		
Reactor waste	2,400		
Decommissioning waste NPP	43,000		
Decommissioning waste PSI	11,000		
Reprocessing waste	5,700	2,000	130
MIR waste	4,000		
Uranium and MOX fuel elements			4,000
Total	75,300	2,000	4,130

Figure 5: Volumes of different waste types in m^3 (assuming a forty-year operating lifetime of the five nuclear power plants and reprocessing of approx. 1000 t of uranium oxide under the existing reprocessing contracts; nagra 1994b and AGNEB 1997). PSI = Paul Scherrer Institute

5 MOX (mixed oxide) fuel elements contain both uranium and plutonium as fuel.

4.2 Disposal concepts

In terms of disposal options within Switzerland, the possibilities shown in Figure 6 can be considered.

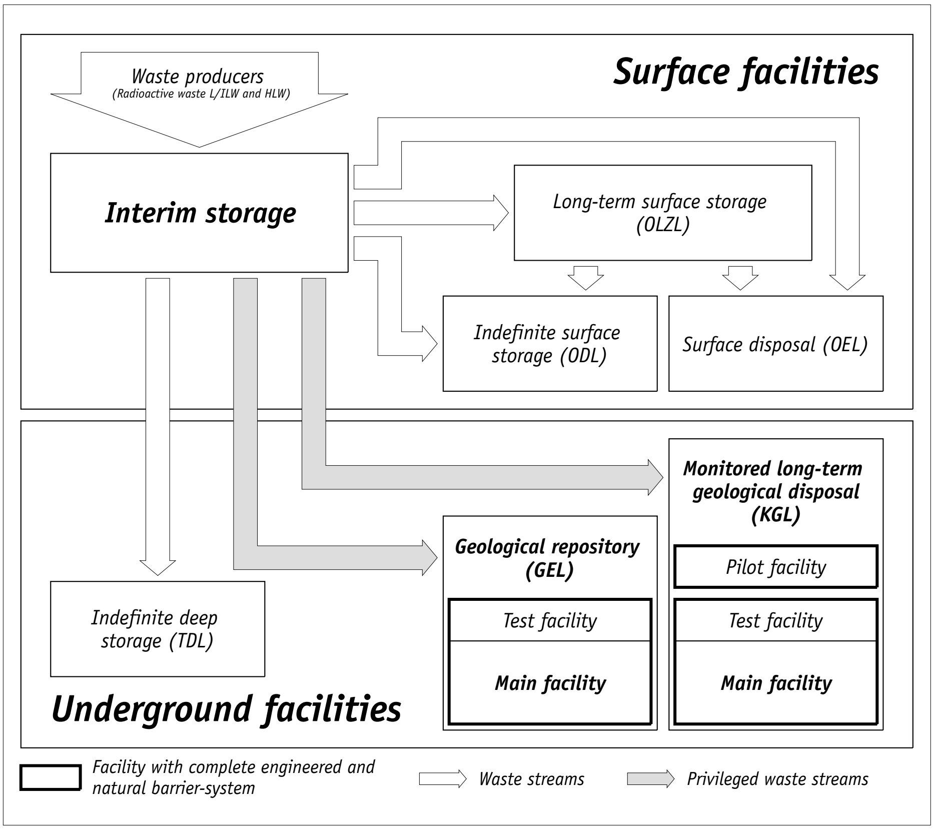

Figure 6: Disposal facilities at the earth's surface (surface facilities) and underground (deep facilities)

4.2.1 Interim storage

Definition and objectives

According to HSK's R-14 Guideline, an interim storage facility is intended for medium-term storage of waste containers in purpose-built halls, with the fixed intention of later removal of the containers from the facility for disposal.

Implementation

In the case of interim storage, protection of man and the environment relies on engineered barriers and measures. The engineered barriers include the waste matrix, the waste container, the storage buildings and associated infrastructure. The measures include monitoring and maintenance of the waste, buildings and infrastructure. The lifetime of an interim storage facility is generally restricted to a few decades.

4.2.2 Indefinite storage

Following interim storage, the waste may be transferred to a surface or an underground disposal facility. The following types come into discussion:

1. *Indefinite storage*

Definition and objectives

Indefinite storage (DL) corresponds to the guardianship concept (Buser 1998). It involves specially constructed facilities at the earth's surface (indefinite surface storage/ODL) or underground facilities (indefinite deep storage/TDL)). An indefinite storage facility is neither backfilled nor sealed.

Indefinite storage should protect man and the environment from the harmful effects of the waste during the necessary storage times, but should also allow monitoring and retrieval at any time without excessive expenditure.

Implementation

Protection is based on a system of engineered barriers and measures (Buser 1998, Nux 1991, Greenpeace 1993). In such a facility, the waste is accessible to authorised persons at all times. The effort involved in retrieving the waste is no greater than that required for emplacement.

2. *Monitored long-term storage*

Definition and objectives

In the final report of the Energy Dialogue working group (Ruh 1998), the concept of monitored long-term storage (LZL) was introduced by environmental protection organisations as part of a new disposal concept for Switzerland.

On the occasion of a hearing with EKRA, representatives of SES, Greenpeace Switzerland and MNA explained their ideas as follows:

- The term "final disposal" is disturbing. "Final" relates solely to the giving up of responsibility by those previously responsible under law and not to the transition of the waste to a permanently safe state.
- The objective of long-term storage should be realised within the framework of a monitored long-term storage facility, by selecting an appropriate design and a dynamic concept. Environmental protection organisations have not yet decided whether the requirement can be met by a geological (deep) facility or a surface facility. However, they have unequivocally distanced themselves from the guardianship concept.

- Monitored long-term storage should provide for control measures and facilitated waste retrieval.
- A surface or near-surface facility should remain as a possibility. However, these would have to offer a similar degree of stability to a deep geological facility. Even in the case of a surface facility, maintenance should not be made a long-term obligation.
- Having monitored long-term storage as a transition phase to a repository is possible. However, it should not be seen in this case simply as a step on the way to a repository, but calls for a new philosophy which would allow monitoring of the facility over hundreds or thousands of years and would require structures to be set up in such a way that they will be functional over these time periods. There are no concrete proposals as to the transition time period.
- The basic problem is that reversibility, as a key feature of monitored long-term storage, cannot be reconciled with final disposal.

The environmental organisations do not consider it their responsibility to define the concept of monitored long-term storage in greater detail. They expect EKRA to take the necessary steps to show how the concept can be brought to a state of development which is comparable with that of disposal in a repository.

Further details on monitored long-term storage can be found in SES (1999). According to this report, disposal is irresponsible because, once the repository has been sealed, there are no provisions for access to the waste. Environmental organisations renew their call for phasing out of nuclear energy, which they believe has to be the first step in any serious waste management strategy.

Implementation

The demands of these organisations for monitored long-term storage contain basic contradictions. On the one hand, the guardianship concept is ruled out, while, at the same time, monitored long-term storage which will last for thousands of years is supported and disposal rejected. To ensure that the concept of monitored long-term storage, as propounded by environmentalists, is not equated with indefinite storage, the following requirements have to be fulfilled:

- In contrast with indefinite storage, there can be no obligation of indefinite maintenance in the case of monitored long-term storage. This means that the storage zones and caverns have to be backfilled at an early stage. Monitoring relates mainly to the evolution and integrity of the facility.

- As long as future generations so wish, the waste emplacement process should be reversible. Retrieval should therefore be facilitated by appropriate measures.
- A monitored long-term storage facility, be it at the surface or deep underground, should be understood as a transitional solution. To ensure long-term safety, it must be possible, at a given time, to transform the facility into a final repository without undue effort or expenditure.

3. *Repositories*

Definition and objectives

The HSK R-21 Guideline defines disposal as follows: "Maintenance-free, permanent isolation of radioactive waste from the biosphere without the intention of retrieval".

A repository should protect man and the environment over the whole time period during which the waste is potentially harmful, without placing any responsibilities on future generations.

Implementation

The majority of research in the field of waste disposal to date has focused on the concept of geological repositories (GEL) and facilities are already in operation in some countries for L/ILW. The protection of man and the environment after backfilling, sealing and closure of the repository is ensured solely by a system of natural and engineered barriers. Once the waste has been emplaced, the repository is closed as quickly as possible. Following this, monitoring of the environment at the surface is foreseen. Besides a main facility, the concept of geological disposal usually includes some kind of test facility.

Test facility

The concept of a test facility was developed for investigating the suitability of a repository. It is operated prior to emplacement of the waste in the main facility and provides input to the definitive safety analysis of the actual repository. Test facilities in zones planned for future emplacement of waste can use real waste or, in an initial period, non-radioactive waste simulators.

Near-surface disposal

Near-surface repositories (OEL) do not come under discussion for HLW in any country for reasons of long-term safety.

Modified disposal concept for Wellenberg

In the run-up to, and following, the referendum in Canton Nidwalden on the Wellenberg repository, demands were made for the possibility to monitor and retrieve the radioactive waste. Based on the concept included in the general licence application, GNW therefore drew up a modified disposal concept (nagra 1998).

The concept allows the repository to be kept open for a limited period of time, without compromising long-term safety. Closure of the facility - whether desired or necessary - can however be realised at any time within a few years. In this case, first the disposal caverns and later the access tunnels are backfilled and sealed. The caverns are designed in such a way that they can be kept open for a period of up to 100 years. During this period, the operating concept provides for easy monitoring of the waste and facilitated retrieval.

The decision on closure of the facility can be left to future generations. The concept of geological disposal is adhered to. A first safety analysis carried out by nagra shows that both operational and long-term safety are assured in the modified disposal concept.

4. *Monitored long-term geological disposal*

Definition and objectives

Following the terms of their mandate, and based on the ideas put forward by the environmentalists, EKRA has developed the concept of monitored long-term geological disposal (KGL; cf. chapter 5).

Similarly to a repository, a monitored long-term geological disposal facility fulfils the requirement for long-term safety, at the same time taking the need for reversibility into account.

Implementation

Besides a main facility, with basic features corresponding to those of a conventional geological repository, the concept also provides for a test facility and a pilot facility.

Pilot facility

Monitoring and control, as foreseen in the concept of monitored long-term geological disposal, can be carried out in the pilot facility, meaning that the main facility is not compromised in any way in terms of its later transformation into a geological repository. In contrast with the test facility, the pilot facility is spatially separated from the main facility and can be operated over a longer time period. The purpose of the pilot facility and the requirements placed on it are discussed in more detail in chapter 5.

4.3 The safety systems

The safety of radioactive waste disposal is ensured by a system of multiple natural and engineered barriers (passive safety system) and by measures (active safety system).

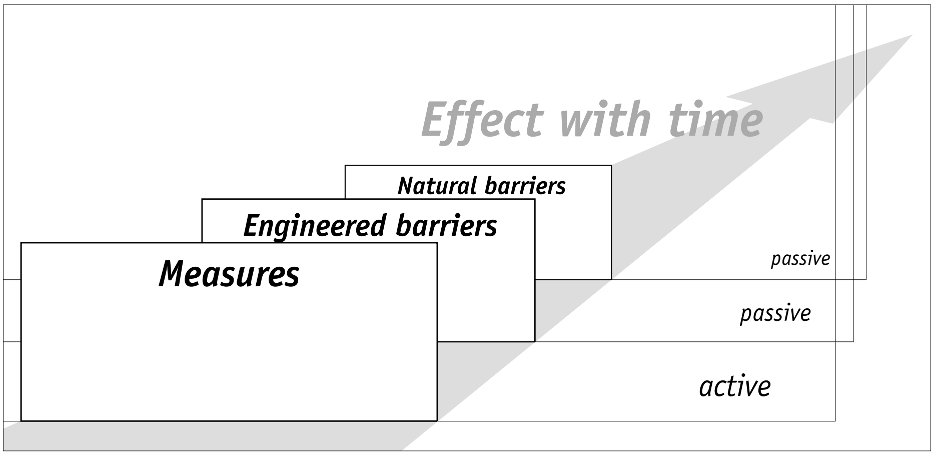

Figure 7: The safety systems for disposal of radioactive waste

The functions to be performed by the barriers are:

- containment of radionuclides for as long as possible (making use of the time for radioactive decay)
- restricting the release of radionuclides
- protection from undesirable human intrusion (non-proliferation, protection in times of crisis) and from external influences (e.g. aircraft impact, floods, earthquakes)

4.3.1 Natural barriers

The natural barriers consist of the geosphere, the host rock and the repository near-field (cf. Appendix 1).

Geosphere

If radioactive substances move from the repository into the host rock, the geosphere has the effect of retarding radionuclide transport to the biosphere. During this time, the toxicity of the radionuclides is reduced due to radioactive decay. In addition, dilution occurs in the geosphere, when the groundwater from the waste disposal zone mixes with other groundwaters.

Host rock

On the long term, the host rock represents the most important migration barrier, retarding radionuclide transport by the mechanisms of sorption and matrix diffusion. The low hydraulic permeability of the host rock also restricts water flow to the engineered barriers.

Near-field

The near-field is that part of the host rock which is in direct contact with the engineered barriers. Simple construction measures in the near-field can prevent undesirable human intrusion into the facility.

a. *Rock mechanics (stability of underground excavations)*

Rock mechanical properties of the host rock

Cavities excavated underground disturb the original state of the rock and are exposed to rock stresses. Rock stresses are determined by the depth-dependent lithostatic pressure and the tectonic forces occurring particularly in young tectonic formations. When excavations are present, these stresses cause deformation of the surrounding rock, which is manifested in the form of more or less strong convergence. The extent of this deformation depends on the plasticity of the rock formation, which in turn is influenced by

- the plasticity of the rock itself
- the degree of fracturing
- substances present in the fractures such as air, water or clay

Some rocks such as clay (Opalinus Clay) or salt show a plastic reaction. This means that, unless appropriate countermeasures are taken, voids in the rock will deform rapidly and may even close within a short time (in the case of salt). In less plastic rocks, e.g. granite, the deformation is significantly smaller. In this case, the rock around cavities may even build up a pseudo-stable condition.

Excavation cross-sections for tunnels and caverns which are smaller and statically optimised are subject to less deformation than large caverns with unfavourable profiles.

Earthquake safety

Based on experience, underground structures are largely earthquake-proof. For geotechnical and hydrogeological effects, reference should be made to the report of the Wellenberg technical working group (TAG 1998).

Support

Caverns in clay can be protected against deformation by rapid backfilling, leaving no voids between the rock and the backfill material. In more elastic rocks, the processes are slower and less intensive and lesser dimensioned support is sufficient. Applied to deep disposal strategies, this effectively means that:

Access tunnels and shafts in clayey rock must be equipped with support which lines the inverted arch of the tunnel floor. The support will have installations for both sealing against and draining groundwater (see below).

The importance of support or lining installations increases with the length of time the cavities have to remain open. In the case of long-term storage, some maintenance will be necessary to keep the tunnel lining in good repair. In facilities for indefinite (deep) storage, the stability of the entire structure depends on the stability of the rock and the lifetime of the installed support.

A comprehensive study carried out at the ETH in Zürich (Wegmüller and Chabot 1997) has shown that the lifetime of underground constructions which are secured in this way can be prolonged using special technologies (drainage installations, concrete additives).

In the actual emplacement caverns, rock stability can be ensured without the need for any massive support by proceeding rapidly from excavation to waste emplacement and complete backfilling of the remaining voids. This is particularly important in a clay host rock (e.g. Opalinus Clay), because lining with concrete is undesirable for geochemical reasons. For other rock types, support could be installed in the emplacement caverns with the intention of keeping them open for a longer period of time. However, this is not imperative because facilitated retrieval is barely affected by the presence of backfill.

In the interests of safety, and particularly to limit the extent of the excavation disturbed zone, the emplacement caverns of a deep facility have to be backfilled as soon as possible The access tunnels should be secured with appropriate support for the duration of the operating and observation period.

b. *Groundwater*

Groundwater in underground constructions

In underground cavities, which are almost always located below the water table, groundwater will be present. However, in the low permeability host rock which would be selected for a deep disposal facility, water flow would be very small. The access tunnels or shafts leading to the facility will, however, pass through "wet", more permeable sections of rock with higher water flow and possibly higher hydraulic pressures. Since the caverns have to be kept dry, any groundwater which cannot be held back by sealing has to be drained or pumped away.

Drainage of groundwater

Drainage of groundwater in underground structures creates a hydraulic sink, i.e. the groundwater flows in from all sides towards the cavity. However, in the low permeability formations being explored as host rocks for radioactive waste disposal, the effect of drainage on the surrounding rock is very small. Nevertheless, for the disposal strategies under discussion, keeping accesses and tunnels open for a longer period of time means that there will have to be some form of drainage or pumping. On the long term, flowing water will impair the facilities and installations and some kind of maintenance will therefore be necessary.

"Drying-out" of the rock

In principle, draining the host rock is undesirable even on a small scale. Drainage leads to partial desaturation of the rock in the immediate vicinity of the underground structures and drainage water can also carry toxic substances to the surface environment.

Pumping away groundwater

In facilities with horizontal access, such as is planned at Wellenberg, water present during the operational phase can be drained away to the surface through the access tunnel. In deep facilities which are accessed by shafts, groundwater has to be pumped to the surface. Failure of the pumps in this case could lead to flooding of the facility and accesses. In the case of both horizontal and vertical access, drainage also entails the risk of introducing toxic substances into the environment.

To prevent the release of toxic substances into the environment, the caverns should be backfilled and sealed shortly after the waste is emplaced. Injection of backfill material into the drainage system may also be necessary.

c. *Ventilation*
Open access routes to the facility require a supply of fresh air. Similarly to drainage water, air can also function as a transport medium for toxic gaseous substances.

4.3.2 Engineered barriers

The engineered barrier system in a waste disposal facility has three components:

Waste matrix

The waste form and packaging represent the first containment measure. Radioactive waste is solidified using suitable materials to form a leach-resistant matrix. In the case of L/ILW, this matrix often consists of cement or bitumen; HLW from reprocessing is enclosed in a glass matrix. If the waste matrix comes into contact with groundwater following corrosion of the container, then the release of radionuclides will be restricted.

Waste container

The waste containers, particularly steel canisters together with any other form of container and infill materials, form the second barrier. They provide complete containment of the waste for a specific time period. Favourable chemical conditions also lead to sorption and limited solubility of radionuclides.

Backfilling of cavities

The voids in the disposal facility are backfilled with materials which restrict water flow to the waste canisters, retard the transport of radionuclides into the geosphere, limit the solubility of radionuclides in groundwater due to favourable chemistry and fix the nuclides to the backfill material by sorption. If the emplacement caverns are not backfilled then an important component of the engineered barrier system is missing.

Different waste types and disposal strategies require different engineered barriers and use of various materials. However, the safety-related considerations are similar. The materials selected for a specific disposal project should not cause any unfavourable geochemical alterations.

4.3.3 Measures

Since measures involve technical, organisational and administrative activities, they place high demands on social institutions. Measures are necessary before, during and after emplacement of the waste and following closure of the facility. They include, in particular, monitoring and control and possible retrieval of emplaced waste.

a. *Monitoring and control*

The effectiveness of monitoring and control measures depends on where and when these are carried out:

- For indefinite storage, monitoring and control are possible at all times and are intrinsic to the safety of the facility.
- For a repository which is (still) open, internal monitoring is possible. The emplacement caverns can be monitored from the access tunnel or from secondary tunnels.
- Once the repository has been closed, only external monitoring is possible, i.e. monitoring from the surface. It is not possible to operate sensors connecting the repository with the surface on the long term as the lifetime of such equipment is too short.

Chapter 5 therefore presents the concept of monitored long-term geological disposal, which foresees construction of a pilot facility. In this facility, key parameters such as repository temperature, pressure conditions, water flow and emissions are measured under conditions similar to those in the main facility. This is possible either in situ or in the immediate vicinity of the emplacement caverns. The pilot facility allows the following:

- checks of the natural and engineered barriers
- repairs or improvements to the engineered barriers with a view to enhancing long-term safety
- clean-up measures in the event of radionuclides escaping into the near-field or the geosphere
- retrieval of waste from the pilot or main facility

b. *Retrieval*

Possible reasons

It may be desirable or necessary to retrieve emplaced waste for various reasons:

- *Safety*: accidents or insufficient facility performance which may, for example, prevent the authorities from granting a permit for closure
- *Test operation*: retrieval from a test facility, validation of models
- *Waste treatment*: re-using resources, separation and transmutation, new solidification technologies
- *New disposal facility*: implementation of a new or 'improved' disposal concept, international solution
- *Other uses of the underground*: raw materials, tunnel construction, etc.

Stages of waste emplacement and retrievability

Three different stages of waste emplacement have to be considered with respect to retrievability:

1. Waste containers in open caverns, either stacked or lowered; access open: very easy retrieval using the same equipment as for waste emplacement.
2. Backfilled and sealed caverns; voids between containers and rock backfilled; access open: easy retrieval using conventional technology. In long-term storage facilities and repositories, the backfill consists of bentonite or bentonite mixtures (HLW) or soft mortars (L/ILW), which can be excavated relatively easily.
3. As for variant 2, but with closed and sealed accesses (repository): retrieval involves increased technical effort and financial investment. In the case of deep facilities, access routes are excavated using conventional underground construction technologies. Particular attention has to be paid to radiation protection. In the facility itself, mining techniques (for example from uranium mining) can be used, or even robots.

For sensitive materials such as fissile plutonium and uranium, facilitated retrievability (variants 1 and 2) represents a long-term risk, e.g. in crisis situations or in the event of misuse of the waste. For reasons of retrievability alone, it makes little sense to keep disposal caverns open. Technically speaking, retrieval is not significantly more difficult once the backfill is in place.

However, there are important technical, economical and psychological differences between retrieval through access tunnels or shafts which are still open and having to open up a sealed repository. Even if there are considerable obstacles to be overcome in variant 3, retrieval is still technically feasible at any time.

4.4 Disposal phases

In this report, the following operative phases are distinguished (Figure 8):

- reconnaissance and planning phase
- construction phase
- operational and monitoring phase
  - testing and emplacement (geological repository, monitored long-term geological disposal and indefinite storage)
  - monitoring (monitored long-term geological disposal and indefinite storage)
- post-closure phase (geological repository and monitored long-term geological disposal)

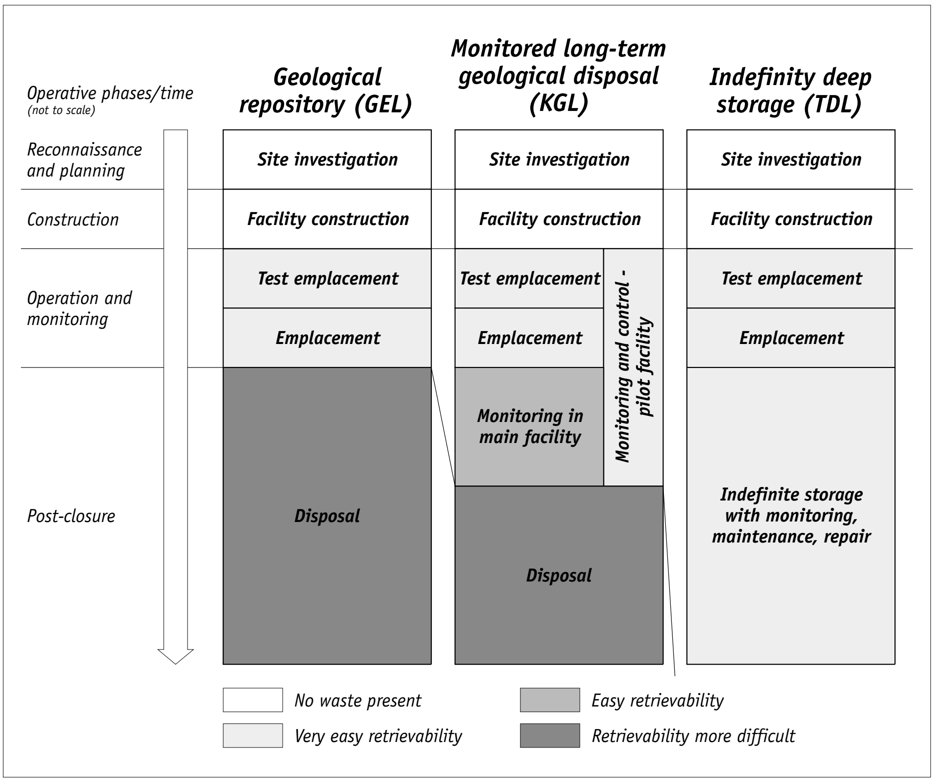

Figure 8: Operative phases of disposal and phase-related effort involved in retrieving the waste from deep facilities

a. *Reconnaissance and planning phase; construction phase*

A range of investigations is necessary before waste can be emplaced in a deep facility:

- Host rock-specific investigations in rock laboratories (e.g. Mont Terri, Wellenberg exploratory drift)
- Intensified fundamental research (national and international programmes), e.g. natural analogue studies to improve the reliability of long-term prognoses
- Setting up an underground laboratory and a test and/or pilot facility at the disposal site

b. *Operational and monitoring phase*

Testing and emplacement

At the beginning of the operational phase, the test facility (geological repository and monitored long-term geological disposal) and the pilot facility (monitored long-term geological disposal only) come into operation. Once the safety of disposal has been demonstrated, waste can be emplaced in the main facility. In the case of a conventional geological repository, the caverns and access tunnels are sealed as quickly as possible. In the case of monitored long-term geological disposal, the emplacement caverns are also sealed but the access routes remain open during the monitoring phase.

Monitoring

Monitoring and control in the case of monitored long-term geological disposal are carried out mainly in the pilot facility and, as far as possible, in the main facility. Further measures are possible in the pilot facility, such as testing the retrievability of waste. At the end of the monitoring phase, the waste is either retrieved from the main facility or the facility is closed and sealed.

During the monitoring phase, a deep facility has to be drained and water pumped away. This results in desaturation of the rock in the direction of the facility and a resultant drop in groundwater pressure. This in turn leads to gas emission from the substances in the water and possibly to drying out of the rock in the disposal zone.

Closure

If monitoring lasts for several decades or more, then a monitored long-term geological disposal facility has to be designed for rapid closure. This is necessary because uncontrollable breakdown of monitoring, for whatever reason, cannot be ruled out.

c. Post-closure phase

Resaturation

After closure of the main facility and transformation into a geological repository, the access tunnels are backfilled and sealed and there is full resaturation of the near-field. The duration of this resaturation period depends on the hydraulic properties of the host rock (permeability) and heat production in the case of HLW.

The following measures are necessary or conceivable once the main facility has been closed.

– Long-term operation of the pilot facility independent of the main facility: monitoring of disposal parameters (early warning, control of system perturbations)
– Remote monitoring of the disposal zone (remote sensing)
– Long-term monitoring of the environment
– Maintaining technical knowledge on radioactive waste and information on waste inventories and disposal locations (avoiding unintentional intrusion into the repository by drilling)
– Protection measures (securing the facility against unauthorised access)

Until radionuclides escape from the backfill, i.e. up to the transition from the engineered to the natural barriers, a time period of several hundred years will elapse in the case of a L/ILW repository and several tens of thousands of years in the case of a HLW repository. The current viewpoint is that, once a facility (including the pilot facility and its access) has been finally sealed, only monitoring of the environment (e.g. measuring the radioactivity of spring water) is to be foreseen.

5. The Concept of Monitored Long-Term Geological Disposal

Chapter 5 develops the concept of monitored long-term geological disposal. The concept is based on the requirements and boundary conditions outlined in chapters 3 and 4.

5.1 Technical design

The following description represents one possibility for the design of a monitored long-term geological disposal facility (KGL).

System elements

The concept of monitored long-term geological disposal comprises the general system elements of a test, main and pilot facility (Figure 9). The actual layout will be decided on a site-specific basis during the course of the project. The three system elements are intended to fulfil the following objectives:

Test facility

The test facility is constructed during and/or immediately after site investigation. It serves as a rock laboratory for carrying out the site-specific studies which are necessary to achieve the safety demonstration required for the operating licence. The test facility can continue to be operated after the main facility comes into operation, as a complement to the pilot facility.

The investigations in the test facility should be targeted towards understanding the safety-relevant processes occurring in the main facility. Parts of the main facility can be reproduced and tested and open questions investigated via specific experiments in the rock laboratory. Heater elements can be used to simulate the heat production of waste, suitable radiotracers can be used to investigate transport processes (migration experiments) and empty waste containers can be used to study chemical processes occurring under disposal conditions.

Main facility

The main facility, where most of the waste is emplaced, is constructed in the host rock. To ensure long-term safety, site selection and the host rock in which the main facility is constructed have to meet the same requirements as those placed on a repository. The architecture of the facility (cavern system and geometry), the installations and the backfilling have to be conceived and realised in such a way that retrieval remains technically straightforward.

Once the waste has been emplaced, the caverns are backfilled immediately. The access shafts and tunnels and areas for monitoring and control of the facility remain open during the monitoring phase and have to be reinforced structurally. During the operational and monitoring phase, the open sections of the facility have to be drained and maintained.

To ensure safety during the longer monitoring phase, provisions have to be made for rapid closure of the facility in times of crisis. Special installations in the access zone (e.g. probes) can be used to observe the near-field during the operational and monitoring phase. However, these must not in any way compromise the long-term safety of the main facility, e.g. by creating direct hydraulic links (short-circuits) to the biosphere.

Pilot facility

The pilot facility fulfils several functions:

– monitoring the long-term evolution of the engineered barriers and the near-field
– verifying the predictive models used to demonstrate long-term safety
– the role of a demonstration facility which allows long-term control beyond the closure of the main facility.

In contrast with the main facility, destructive experiments can be carried out in the pilot facility once certain time limits have expired, in order to obtain more accurate information on the components of the disposal system. Since the integrity of the whole or parts of the pilot facility can then no longer be guaranteed, any waste containers would have to be retrieved for emplacement elsewhere.

Together with the results from the test facility and from the construction and operational phase of the main facility, the results from the pilot facility provide the key input for confirming long-term safety. Detailed evaluation of the results is a prerequisite to obtaining permission to close the main facility.

The investigations in the pilot facility also provide a basis for deciding whether waste has to be retrieved from the main facility for safety reasons.

Based on the observations in the pilot facility, the following activities can be carried out in the main facility:

– monitoring of the engineered and, to some extent, natural barriers

- repairs and improvements to the engineered barriers
- clean-up measures in the event of unexpected escape of radionuclides into the near-field or the geosphere
- retrieval of waste

The pilot facility is constructed and operated before the main facility and the two must be completely isolated hydraulically from one another.

5.2 Implementation

A prerequisite to the construction of a monitored long-term geological disposal facility is successful completion of site investigations. Construction, operation and proper closure of the facility also require independent project and control structures for ensuring the quality of planning and implementation and allowing corrective measures to be taken if required. Openness, transparency and technical competence are the key parameters for building public confidence and acceptance. This in turn requires an exemplary information and communication system, which has to be maintained and followed over the entire operating period of the facility.

The project structures have to be secured as far as possible against social crises. Economic depression, war, terrorism and epidemics are particularly threatening scenarios. Because of the large extent of potential damage, these threats require thorough prevention measures.

Reconnaissance and planning phase

The reconnaissance and planning phase comprises site investigation and characterisation and planning of the different components of the facility. At the same time, the programmes and systems for work supervision and quality control are specified. If the results of the site investigation are positive, planning and construction can then begin.

Construction phase

The first step in the construction phase is to build the test and pilot facilities. Construction of the main facility proceeds in a stepwise manner during the operational and monitoring phase.

Operational and monitoring phase

The operational and monitoring phase begins with operation of the test and pilot facilities. Accident management has to be initiated at the beginning of this phase.

Test facility: Operation of the test facility is aimed at providing input for the safety demonstration for the main facility. A definitive design for the main facility can be selected based on information obtained in the test facility.

Pilot facility: Monitoring and control of the disposal facility and the near-field are planned and realised in the pilot facility. The information obtained can be transferred to the main facility and, if necessary, can be verified in situ.

Main facility: If the results of the test operation are positive, the next stage can be initiated. The access and operation areas of the main facility are constructed in full. The emplacement areas are initially constructed only in part and further caverns can be constructed and tested depending on space requirements.

Construction requires careful supervision to ensure quality of work. At the same time, the overall planning of active measures is initiated.

Once the caverns have been cleared for use, the beginning of waste emplacement signals the actual operation of the main facility.

As soon as the waste has been emplaced, the caverns of the main facility are backfilled and sealed immediately. Access and service tunnels remain open to facilitate access to the disposal zone and the surrounding near-field. The open accesses and tunnels require to be drained. During this phase, the waste can be retrieved without any excessive technical effort or financial cost. The system for management of accidents is still effective.

Closure and post-closure phase

Definitive closure of the access and service tunnels of the main facility is carried out only when the operational and monitoring phase is complete; this may be several decades to more than a hundred years. During this period, safety assessment models can be validated. Definitive closure of the main facility requires a further safety analysis.

It is conceivable that the pilot facility may be kept open for a further period and actually closed later than the main facility. This is a decision for future generations.

Tasks of a long-term nature, such as archiving and transfer of technical knowledge and possibly also monitoring using passive systems, follow after closure of the disposal facility and should become the responsibility of the public domain.

The status of research on the different elements of a monitored long-term geological disposal facility is less advanced than for a geological repository. The need to make up the difference applies mainly to the construction of a pilot facility and the safety systems of the disposal facility during the operational and monitoring phase.

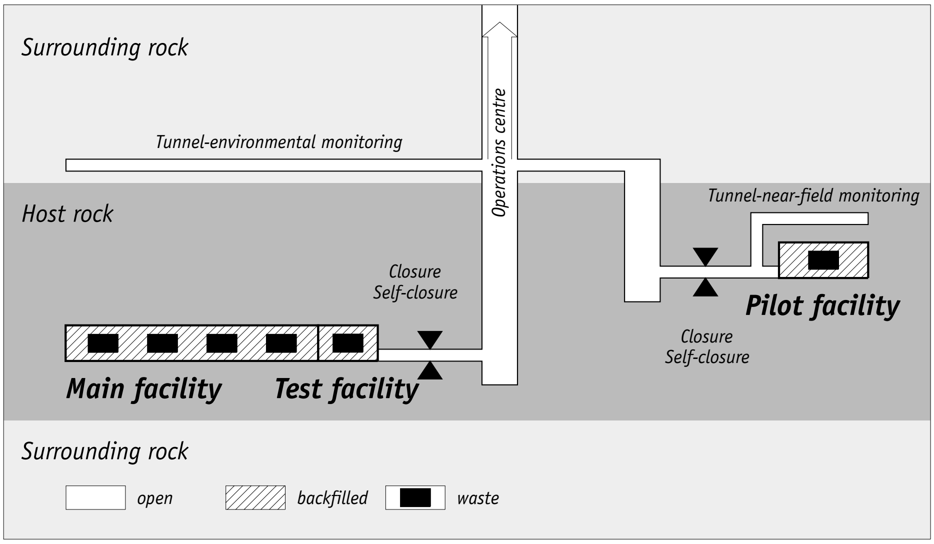

Figure 9: Schematic concept of the monitored long-term geological disposal facility: system elements

5.3 Planning of measures

Chapter 5.2 outlined a possible approach for technical-scientific realisation of the monitored long-term geological disposal facility. The following discussion highlights the importance of coherent planning of measures. The key elements of such planning are:

- Ensuring a high level of quality for general planning and for specific sub-programmes (facility design, backfilling, sealing, closure, etc.)
- Monitoring and control programmes for the construction, operation, monitoring and post-closure phases, as well as for all relevant parts of the facility, engineered systems and the environment (particularly the near-field)
- Quality assurance programmes for the different phases and components of the programme (construction, monitoring, control, data management, etc.)
- Accident management (including retrieval of the waste), starting from the construction phase
- Securing financial resources, ensuring the availability of the necessary information on the facility, marking the presence of the facility and passing on specialist information
- Information and communication as the key aspects of confidence-building

6. Evaluation of Disposal Concepts

In this chapter, the disposal concepts presented in chapters 4 and 5 are subjected to a comparative evaluation. The following concepts are considered:

- *indefinite surface storage (ODL)*
- *long-term surface storage (OLZL)*
- *surface disposal (OEL)*
- *indefinite deep storage (TDL)*
- *monitored long-term geological disposal (KGL)*
- *geological repository (GEL)*

These concepts differ mainly in their respective safety systems. Figure 10 gives an overview of the characteristic barriers and measures for the different concepts (shaded grey). The effectiveness of these barriers and measures as a function of time is discussed in chapter 4.

		Surface facilities			Underground facilities		
		ODL	OLZL	OEL	TDL	KGL	GEL
Measures		■	■		■	■	
Engineered barriers	Waste matrix and container	■	■	■	■	■	■
	Backfill		■	■		■	■
Natural barriers	Near-field, host rock, geosphere					■	■

Figure 10: Safety systems for the different disposal concepts. Grey: barrier or measure is part of the concept

6.1 Basis for the evaluation

a. Procedure

To compare the different concepts, it is necessary to perform an integrated consideration of safety which covers all phases subsequent to construction:

- Operational and monitoring phase with
  - testing and emplacement
  - surveillance (monitoring and control)
- Post-closure phase

A two-stage procedure is followed for the evaluation:

- Safety has top priority as an evaluation criterion. The first point to be investigated, therefore, is what level of safety can be achieved in the operational and monitoring phase and in the post-closure phase. The investigation assumes that all disposal concepts aim for a high level of safety. For such an integrated consideration of safety, both the level of safety achieved and the time period over which residual risks remain have to be taken into account. Within the context of the present study, this can be done only qualitatively.
- After this, other social criteria such as freedom of action, the producer pays principle and acceptance are included in the evaluation.

b. Evaluation criteria

In chapter 3, the values and objectives of radioactive waste disposal are defined and organised hierarchically. Highest priority is assigned to safety:

- safety of man and the environment
- freedom for every generation, fairness between social and population groups and between generations
- observing the producer pays principle
- acceptance

c. *Definition of safety areas*

Generally speaking - and without setting any priorities - the following areas of safety can be distinguished:

1. *Worker safety*
   Objective: protection of workers
   Comprises: conventional work safety and radiation protection
2. *Accidents*
   Objective: protection of man and the environment from acute, unintentionally caused accidents
   Comprises: conventional accident safety and radiation protection
   2.1 *Safety from internal accidents*
   Examples: fire, explosion, deflagration, collapse
   2.2 *Safety from external events*
   Examples: earthquakes, meteorite impact, meteorological events, flooding, aircraft impact
3. *Security*
   Objective: protection from intentional human intrusion
   Comprises: protection from sabotage or other actions of third parties
4. *Emissions*
   Objective: protection of man and the environment from chronic effects during the operation of a facility
   Comprises: conventional imission protection and radiation protection for persons not exposed in work circumstances, including the case of unforeseen chronic escape of radioactive materials from a facility
5. *Long-term safety*
   Objective: protection of man and the environment from chronic effects after operations are complete

Specific methods are available for investigating these five areas of safety, but these are not considered in greater detail in this report. The following evaluation is qualitative in nature and is not comparable with a safety analysis in the sense of the nuclear legislation.

d. *Evaluation of natural and social systems*

Earth science investigations show that geology is always full of surprises. Geological predictions will always contain an element of uncertainty, as will predictions of the long-term behaviour of engineered systems.

If the critical question about the evolution of scientific knowledge and changing world-views is posed to natural scientists - namely to geologists - then, with equal justification, the same question must also be asked of social scientists.

Prediction of socio-political developments is generally orders of magnitude more uncertain (see chapter 3) than predictions of geological events. The only exceptions to this are sudden changes such as earthquakes, whose occurrence can be predicted statistically but not deterministically. Contrary to convictions in the tradition of dialectic materialism, the society of the future is neither controllable nor predictable on the long term. One example of this is the shifting of borders in Europe in the last 200 years.

This situation means that disposal concepts which rely, on the long term, on social structures have little chance of success in the context of safety analysis.

Measures can contribute to the safety of radioactive waste disposal but they do not represent a viable alternative to comprehensive investigation and assurance of the long-term safety of a facility. By the same token, installations for monitoring and control should not have the effect of compromising the passive safety of a facility.

6.2 Evaluating safety

6.2.1 Safety areas

a. *Worker safety*

Operational and monitoring phase

As long as the caverns and other areas of a facility remain open, worker safety during emplacement and operation depends more on organisational measures than on the disposal concept itself. In this respect there is no significant difference between the different concepts. For example, the comprehensive analyses and evaluations of worker safety and accident prevention for the centralised interim storage facility (ZWILAG) in Würenlingen have shown that the facility meets legal requirements (HSK 1995, HSK 1999, ZWILAG 1994, ZWILAG 1997).

Once emplacement, monitoring and testing are complete, the caverns and other areas of monitored long-term disposal facilities and repositories are backfilled. In repositories, accesses are also backfilled and sealed. After this, no further work activity is necessary in a repository.

A geological repository offers optimum shielding of radioactive waste. In the case of monitored long-term storage (including monitored long-term geological disposal), higher requirements than in the case of a geological repository are thus placed on facilities in terms of operational radiation protection. On the one hand, there is more maintenance and repair work and, on the other hand, some engineered barriers are not yet effective prior to closure in the case of monitored long-term geological disposal.

Figure 11 gives a qualitative estimate of the safety offered by the different waste management concepts during the operational, monitoring and post-closure phases.

Operational and monitoring phase Testing and emplacement (approx. 30 - 50 years)	**Surface facilities**			**Underground facilities**		
	ODL	**OLZL**	**OEL**	**TDL**	**KGL**	**GEL**
1. Worker safety						
2.1. Accident prevention, internal events						
2.2. Accident prevention, external events						
3. Security						
4. Emissions						

Operational and monitoring phase Monitoring (decades to centuries)	**ODL**	**OLZL**	**OEL**	**TDL**	**KGL**	**GEL**
1. Worker safety			No activity			No activity
2.1. Accident prevention, internal events	**Measures**	**Measures**		**Measures**	**Measures**	
2.2. Accident prevention, external events						
3. Security						
4. Emissions						

Post-closure phase and indefinite operation (up to more than 100,000 years)	**ODL**	**OLZL**	**OEL**	**TDL**	**GEL + KGL**
1. Worker safety		No activity	No activity		No activity
2.1. Accident prevention, internal events					
2.2. Accident prevention, external events					
3. Security					
4. Emissions					
5. Long-term safety					

Low safety level Restricted safety level High safety level

Figure 11: Qualitative estimate of the safety of different waste management concepts

In non-backfilled caverns and other areas of an indefinite storage facility and up to the time when the caverns are backfilled in the modified disposal concept for Wellenberg, worker safety depends largely on organisational measures and maintenance of the facility. This applies, for example, to the structural strength of the disposal zone, the integrity of the structures or the condition of electrical installations. The safety offered by the engineered barriers is reduced at this stage (Figure 11).

Post-closure phase and indefinite operation

After several hundred years, operations continue only in indefinite storage facilities and the question arises as to the degradation of these facilities. It cannot be foreseen how future generations will maintain active measures and, in this sense, worker safety is not ensured from a present-day point of view.

Conclusion

If worker safety is compared for all phases of emplacement, then a geological repository comes out best, given the better protection from emissions; monitored long-term geological disposal comes second.

b. Accidents

Operational and monitoring phase

Internal triggers for accidents are events such as fire, explosion/deflagration, technical failure and operational accidents. External triggers are events such as aircraft impact, meteorite impact, meteorological processes, earthquakes and floods.

An indefinite storage facility can be compared with an interim storage facility, although the lifetime of the latter should be restricted to a few decades. Detailed investigations show that, given appropriate design and organisation, an interim storage facility can be operated safely over a few decades. According to current legislation, an emergency organisation has to be maintained for dealing with accidents.

Deep facilities generally offer better passive protection than surface facilities. Once a geological repository and a monitored long-term geological disposal facility have been closed, the integrity of the waste forms and the emplacement areas is better ensured than in the open areas of a deep facility for indefinite storage. In the case of indefinite and long-term storage, monitoring, maintenance and facilitated waste retrieval are included as additional measures in the case of accidents; however, the associated risk tends to increase due to delaying of closure. After a period of decades to more than a hundred years, the question arises as to the stability of accesses and other structures and the possibility of flooding in the event of failure of the drainage system.

c. *Security*

Operational and monitoring phase

Security has to be determined by short-term analyses since the risk situation varies with social boundary conditions and is difficult to predict over longer time periods. Security is an issue which has to be resolved time and time again in a flexible manner. Important questions arise particularly in connection with the proliferation problem. This topic is the subject of international discussion on both a political and technical level and has been regulated by several international conventions.

Already in the operational phase, underground facilities offer better security via technical measures than surface facilities (Figure 11). For example, in the event of war the caverns and accesses could be closed relatively quickly.

Post-closure phase and indefinite operation

In the case of a geological repository, security after closure is guaranteed by the more difficult access. Only planned retrieval at significant cost would allow access to the waste. Since no closure is foreseen in the case of indefinite storage, sensitive material can be retrieved relatively easily at any time.

d. *Emissions*

During emplacement

Similarly to worker safety, protection from emissions during emplacement and operation is more or less the same for all concepts. The different components of the facilities are open and have to be ventilated.

After emplacement

Once the emplacement work is complete, the situation evolves somewhat differently:

- Open indefinite storage facilities have to be ventilated, which means that radioactivity could enter the atmosphere. On the other hand, escape of radionuclides with water is rather unlikely as long as the facility is maintained and drained appropriately. It is safe to assume that this is possible over periods of several decades.
- In the case of long-term surface storage, surface disposal and GNW's modified disposal concept for Wellenberg, an escape of radioactivity after backfilling is less likely than in the case of indefinite storage.

- For monitored long-term geological disposal, the emplacement caverns are backfilled immediately but the accesses and the pilot facility remain open. This creates a hydraulic sink which can lead to movement of toxic substances with water in the direction of the sump. The level of emissions in this case depends, to a large extent, on the permeability of the rock, the integrity of the waste packages and the duration of the observation phase. The concentration of toxic materials in the sump is a measure of the integrity of the facility.
- In a geological repository, there is no hydraulic sink once the caverns and accesses have been backfilled. The transport of toxic substances by gas or flowing water is therefore greatly restricted.

Post-closure phase and indefinite operation

After backfilling and sealing, the monitored long-term geological disposal facility and the modified disposal concept for Wellenberg offer optimum fulfilment of the requirements for restriction of emissions, similarly to the case of a geological repository. In the case of surface facilities and indefinite deep storage, the question arises as to the integrity of the facility structures over the time period considered.

e. *Long-term safety*

Post-closure phase and indefinite operation

For all surface facilities, long-term safety cannot be ensured because of the risk of natural catastrophes, erosion processes and events such as war. Since it cannot be shown that society will remain stable on the long term, it is questionable whether surface facilities and deep facilities for indefinite storage can be operated safely over long time periods. For these concepts, it would be necessary, after a certain period of time, to renew containment or recondition the waste.

If the option of reprocessing is abandoned and there is direct disposal of spent fuel, there could be free access to the waste in the case of surface facilities and deep facilities for indefinite storage, which is contrary to the principle of non-proliferation.

Based on current knowledge, long-term safety can be guaranteed only by a combination of natural and engineered barriers such as that found in a geological repository or in a monitored long-term geological disposal facility that has been transformed into a repository. The depth of the geological repository beneath the earth's surface provides protection from natural catastrophes and erosion and undesirable human intrusion becomes very difficult. The extremely slow processes occurring in the lithosphere provide effective protection from the migration of radionuclides until they have decayed to a level which is no longer dangerous.

6.2.2 Evolution with time

a. Long-term safety

Surface facilities and facilities for indefinite storage

For a time horizon of several hundred to more than a hundred thousand years, long-term safety is of the highest priority. This means that surface facilities and deep facilities for indefinite storage no longer come into consideration. The main reasons for this are:

- The integrity of surface constructions and the open deep facilities for indefinite storage cannot be taken for granted
- Social evolution cannot be predicted and the measures required for ensuring safety cannot be guaranteed

GEL and KGL

This means that only geological repositories and monitored long-term geological disposal can be considered as acceptable concepts. Important factors for their evaluation are:

- In the case of geological repositories, a mature philosophy and the technical knowledge required for performance assessment already exist
- The safety requirements attached to monitored long-term geological disposal are basically the same as for a geological repository. However, compared to a geological repository, monitored long-term geological disposal has a somewhat modified architecture aimed, among other things, at providing for easier retrieval of the waste. Detailed investigations are necessary to determine the extent to which the long-term safety of monitored long-term geological disposal is influenced by the preceding observation phase with monitoring and control measures.

Modified disposal concept for Wellenberg

In many respects, the modified disposal concept for Wellenberg is similar to the concept of monitored long-term geological disposal developed by EKRA. However, there are differences. As part of the Energy Dialogue on waste management, reference has already been made to the fact that keeping emplacement caverns and accesses open for longer periods of time would lead to higher groundwater flow than in the case of a sealed facility. Backfilling and sealing of the individual caverns should therefore happen soon after emplacement. Another difference relates to the construction and operation of the pilot facility, as proposed by EKRA for the concept of monitored long-term geological disposal.

b. *Medium-term safety*

GEL and KGL

Following exclusion of surface facilities and deep facilities for indefinite storage on the basis of their inability to meet the criterion of long-term safety, only geological disposal and monitored long-term geological disposal are evaluated in terms of the level of safety they offer over periods of several decades to centuries. The following points have to be considered:

– Based on the extended observation phase, monitored long-term geological disposal fulfils the criterion of reversibility (possibility of monitoring and control, retrieval and re-use in the case of HLW) better than a geological repository.
– This advantage of monitored long-term geological disposal over geological disposal has to be weighed against the uncertainty regarding social stability over longer time periods (decades to centuries). This would mean a greater investment of effort towards ensuring security and operational safety during the observation phase, which would lead to increased costs and effort for the monitoring authority.

c. *Short-term safety*

GEL and KGL

During the operational phase, which lasts for thirty to fifty years, there is no significant difference between the concepts of geological disposal and monitored long-term geological disposal.

6.3 Overall comparative evaluation

As shown in chapter 6.2, surface facilities and deep facilities for indefinite storage cannot ensure a sufficient level of safety. Therefore, only geological disposal and monitored long-term geological disposal are compared.

a. *Safety of man and the environment*

Based on current knowledge, a geological repository ensures the long-term safety of man and the environment.

Monitored long-term geological disposal, on the other hand, offers the possibility during the operational and observation phase to identify and react to unforeseen incidents. However, when the accesses are kept open, drainage water and gas escape can cause emissions to the environment. There are also uncertainties regarding future social developments. The main question is how long society will be capable of monitoring such a facility and closing it if necessary.

Optimisation between the two options should be investigated within the context of concrete projects.

b. *Freedom for all generations and fairness between different social and population groups and generations*

Freedom of decision

The fact that future generations will not be placed under any obligation to care for the waste speaks in favour of a geological repository.

Compared with this, monitored long-term geological disposal opens to future generations the possibility, to a certain extent, to correct earlier unwise decisions and to apply new knowledge to the waste disposal problem.

Fairness

Considerations of fairness, e.g. distribution of burdens, are necessarily restricted to the present-day situation and do not allow the two concepts to be compared over longer time periods. On a regional basis, for example, the burdens borne at the location of the interim storage facility (no long-term safety) and the potential sites for a geological repository or a monitored long-term geological disposal facility at Wellenberg or in the north of Canton Zürich have to be weighed against one another.

c. *Observing the producer pays principle*

For both concepts, observing the producer pays principle can be ensured in the same way by:

– securing the financial means for disposal today, independent of the fluctuating economic climate
– rapid construction of the facility

d. *Acceptance*

Public debate should be encouraged with a view to answering the acceptance question. The respective advantages and disadvantages of a geological repository and a monitored long-term geological disposal facility have to be weighed against one another and evaluated.

The choice between a geological repository and a monitored long-term geological disposal facility should be made as part of an optimisation procedure between two complementary concepts. When deciding, the safety of man and the environment have priority over all other criteria at all times.

7. Conclusions and Recommendations

7.1 Conclusions

Evaluation of the different waste management concepts has led EKRA to reach the following conclusions:

Interim storage

1. The safety systems of **interim storage facilities are designed for short storage periods**; they do not fulfil the key requirement of long-term safety.

Facilities at the surface and facilities for indefinite storage

2. **Waste disposal facilities located at the surface** *(for indefinite storage, long-term storage and disposal)* and open facilities at depth *(for indefinite deep storage)*, all of which require to be monitored, also **fail to meet the long-term safety criterion**.

Geological disposal (GEL)

3. Based on current knowledge, **geological disposal is the only method** for isolating radioactive waste **which fulfils the requirement for long-term safety** (up to more than 100,000 years). This concept is based on a combination of engineered and natural safety barriers which ensure isolation of the waste. Reversibility, i.e. the possibility of retrieving the waste from a closed repository, is feasible in principle but does not form an integral part of the concept.

Monitoring, control and retrievability

Concept of monitored long-term geological disposal (KGL)

4. **Social demands** concerning waste disposal **are oriented towards the principle of reversibility**. EKRA has therefore developed the concept of *monitored long-term geological disposal*, which combines disposal with the possibility of reversibility. In addition to the actual waste emplacement facility (the main facility), the concept foresees construction of a test facility and a pilot facility and a phase of monitoring and facilitated waste retrieval prior to geological disposal. In this sense, the concept of monitored long-term geological disposal takes into account requirements for both long-term safety and reversibility. Provided there is no reason to retrieve the waste beforehand, geological disposal will thus be realised in a stepwise manner.

Comparison of GEL and KGL

5. The way in which the concept of **geological disposal is extended to include elements of monitored long-term geological disposal** is determined by safety considerations.

The advantages, in terms of safety, of monitored long-term geological disposal during the monitoring phase are:

- possible enhancement of safety as a result of increased knowledge and technological advances
- early recognition of unexpected and undesirable developments
- easy retrieval of the waste or, if necessary, repair of the facility

Possible disadvantages of monitored long-term geological disposal during the monitoring phase are:

- longer exposure times, especially for operating personnel
- an increased risk due to undesirable intrusion by third parties
- negative consequences arising from unforeseen socio-political developments which are difficult to predict (such as war, system changes, social and technological collapse, epidemics)

With regard to the stepwise procedure leading from monitored long-term geological disposal to geological disposal at a later stage, there are still open questions which require to be answered within the context of concrete projects and generic analyses.

Compared with final geological disposal, introducing the concept of monitored long-term geological disposal would involve higher construction and operation costs.

In the event that in-depth investigations as part of concrete projects show that the concept of monitored long-term geological disposal can provide a level of safety which is comparable with that of geological disposal, then the former should be the preferred option given the easier reversibility which it offers.

Waste management programmes

6. Waste management programmes in Switzerland:

HLW/TRU

HLW/TRU programme: **Based on current knowledge, the host rock currently under investigation (Opalinus Clay) is suitable in principle** for both a geological repository and a monitored long-term geological disposal facility. Research requirements relate to providing input for later geological disposal and to obtaining more detailed information on the operational and observation phase of monitored long-term geological disposal.

L/ILW

L/ILW programme: **In many respects, the modified disposal concept for Wellenberg is comparable with the concept of monitored long-term geological disposal**. The key differences are the rapid backfilling of the disposal caverns in the latter case and the construction of a pilot facility for monitoring and control.

Site characterisation at Wellenberg should be continued with the construction of an exploratory drift.

7.2 EKRA's mandate

1. *To compare the concepts of geological disposal, monitored and retrievable long-term storage, indefinite storage and interim storage*

Active and passive safety

Only through a combination of engineered and natural barriers (passive safety system) can the long-term safety of waste disposal be ensured. The only facilities which come into question from this point of view are deep geological waste emplacement facilities with sealed caverns (geological repositories and monitored long-term geological disposal facilities in the sense of this report). Facilities located at the surface, namely for interim and indefinite storage, and deep facilities for indefinite storage with open caverns do not come into question as long-term solutions.

Monitoring and control

On one side, provisions for monitoring and control in the waste disposal zone contradict the requirement for long-term safety, but they do have a strong ethical foundation.

Retrievability

Retrievability is part of the requirement for reversibility and can be facilitated by appropriate planning measures. However, these measures have the effect of increasing the risk of undesirable access to the waste.

Geological disposal

Monitored long-term geological disposal

EKRA comes to the conclusion that the safety standards, as they are embodied in the concept of geological disposal, must be adhered to. To allow aspects of monitoring, control and facilitated waste retrieval to be considered within such a framework, EKRA has developed the concept of monitored long-term geological disposal; this concept includes both a test and a pilot facility as well as special organisational and institutional measures. Monitoring and control can be realised in the pilot facility outside the main waste emplacement area. The pilot facility can be operated before, during and after emplacement of the waste in the main facility.

2. *L/ILW project at Wellenberg and HLW/TRU project in Northern Switzerland*

Based on current knowledge, the host rocks being investigated would meet the requirements for both geological disposal and monitored long-term geological disposal. These projects should therefore be pursued and investigated in terms of suitability for both concepts.

3. Legislation

- In light of the above findings, the new nuclear energy law and other fundamental legal provisions, e.g. the law on mining prerogative, should consider geological disposal as setting the standard for long-term safety for all waste types. The possibilities for monitoring, control and facilitated waste retrieval should be documented by project planners as they apply to the concept of monitored long-term geological disposal.
- Financing of waste management activities should be assured immediately in the form of a special fund.

7.3 Recommendations

The overriding objective of nuclear waste management is to ensure unlimited protection of man and his environment from the hazards presented by radioactive waste. A geological repository is the only method of dealing with waste which meets this objective. Societal demands, particularly in terms of monitoring, control and retrievability, are taken into account in EKRA's concept of monitored long-term geological disposal.

Based on the terms of its mandate, EKRA recommends the following course of action:

Public debate

a. Public debate on the issue of nuclear waste management is to be encouraged.

Nuclear energy legislation

Nuclear energy legislation

b. Geological disposal for all waste types should be foreseen in the legislation. Project planners should be obliged to document, in ongoing projects, aspects of monitoring, control and facilitated waste retrieval as they apply to the concept of monitored long-term geological disposal.

c. Steps should be taken today to ensure that the waste management programme is financially independent of the nuclear power plant operators and the necessary institutional changes should be set in motion.

Wellenberg L/ILW project

L/ILW project at Wellenberg

d. Based on currently available information, the Wellenberg site fulfils the criteria for both geological disposal and monitored long-term geological disposal. The project should be pursued, whereby the 'modified disposal concept Wellenberg' can serve as the starting-point. The possibilities for monitored long-term geological disposal should be investigated from the point of view of location and layout of a pilot facility. The first action at Wellenberg, however, is to take the necessary steps towards constructing an exploratory drift.

HLW/TRU programme

HLW/TRU programme

e. The host rock currently under investigation - Opalinus Clay - is suitable in principle for both geological disposal and monitored long-term geological disposal. Once the Entsorgungsnachweis (project demonstrating the feasibility of disposal) has been accepted, site characterisation should move forward and facility planning and site investigation should be initiated. International disposal options are in no way a replacement for solving the disposal problem within Switzerland itself.

Time schedule for realisation

Time schedule

f. A time schedule for realising both projects should be prepared and progress should be checked at regular intervals.

Bibliography

(Note: literature references are available only in the language of the title appearing below)

- AGNEB (1997): 19. Tätigkeitsbericht der Arbeitsgruppe des Bundes für die nukleare Entsorgung, Bundesamt für Energie.
- AGV (1998): Arbeitsgruppe Volkswirtschaft, Die volkswirtschaftlichen Auswirkungen eines SMA-Lagers Wellenberg – Kosten-Nutzen Analyse. Bundesamt für Energie, Bern.
- Aktionsplan (1997): Aktionsplan Umwelt und Gesundheit, Bundesamt für Gesundheit/Bundesamt für Umwelt, Wald und Landschaft, Bern.
- ANDRA (1997): Agence Nationale pour la Gestion des Déchets Radioactifs, Laboratoire de recherche souterrain Est - état des connaissances et programme d'experimentation.
- Bär, R. (1997): Der Effizienzpfad aus der atomaren Sackgasse (Zur Lagerung radioaktiver Abfälle aus Atomkraftwerken). Neue Zürcher Zeitung, 27.2.1997.
- Barde, J.-P. (1991): Economie et politique de l'environnement, Paris.
- Buser, M. (1997): Which is more stable: a rock formation or a social structure? Nagra bulletin No. 30, August 1997.
- Buser, M. (1998): "Hüte"-Konzept versus Endlagerung radioaktiver Abfälle: Argumente, Diskurse und Ausblicke. HSK Würenlingen.
- Buser, M. & Wildi, W. (1981): Wege aus der Entsorgungsfalle. Schweizerische Energiestiftung (Zürich), Report 12.
- CNE (1998): Commission Nationale d`évaluation relative aux Recherches sur la Géstion des Déchets Radioactifs instituée par la loi 91-1381 du 30 décembre 1991: Thoughts on Retrievability. Executive Summary, Paris.
- CNE (1999): Commission Nationale d`évaluation relative aux Recherches sur la Géstion des Déchets Radioactifs instituée par la loi 91-1381 du 30 décembre 1991: Rapport d' Evaluation N° 5, Paris.
- CRWMS (1998): Civilian Radioactive Waste Management System, Total System Description. Revision 1.
- Damveld, H. & Van den Berg, R. (1999a): Social and ethical aspects of retrievable disposal. Working paper.
- Damveld, H. & Van den Berg, R. (1999b): Atomabfall und Atomethik. In: W. Neumann: Von Lingen nach Ahaus. EuKo-Info-Redaktion, Gronau.
- Dodd, D.H., Grupa, J.B., Heijdra, J.J. & Prij, J. (1998): A repository design for the retrievable disposal of radioactive waste in rock salt. ECN-Report, Series RX, 98-022, Petten.
- DOE (1999): US Department of Energy. A Roadmap for Developing Accelerator Transmutation of Waste (ATW) Technology. A Report to Congress.- DOE/RW-0519. Washington, D.C.
- EIA (1999): Energy Information Administration, Annual Energy Review 1998.
- Gervers, J. H. (1993): Bericht der Arbeitsgruppe Standortvorauswahl. Appendix A. Experience of different countries in site selection - case studies. A3 U.S.A. In: Niedersächsisches Umweltministerium (Hrsg.): Endlager-

Hearing Braunschweig. Tagungsband II, S. 312-322, Hannover (Internationales Endlager-Hearing 21.-23. September 1993 in Braunschweig).

- Greenpeace (1993): Trittst im Morgenrock daher, seh ich dich im Strahlenmeer, Greenpeace Schweiz.
- Hammond, Ph.R. (1979): Nuclear waste and public acceptance. American Scientist, Vol. 67.
- Han, W. K., Heinonen, J. & Bonne, A. (1997): Radioactive Waste disposal: Global experience and challenges. IAEA-Bulletin, 39/1, Vienna.
- HSK (1995): Hauptabteilung für die Sicherheit der Kernanlagen, Gutachten zum Gesuch der ZWILAG um Erteilung der Betriebsbewilligung für Bau und Betrieb des Zentralen Zwischenlagers für radioaktive Abfälle, HSK 27/12, Dezember 1995.
- HSK (1999): Hauptabteilung für die Sicherheit der Kernanlagen, Gutachten zum Gesuch der ZWILAG um Erteilung der Betriebsbewilligung für die Konditionierungsanlage sowie für die Verbrennungs- und Schmelzanlage des Zentralen Zwischenlagers für radioaktive Abfälle in Würenlingen, HSK 27/45, August 1999.
- IAEA (1971): Proceedings of the Fourth International Conference on the Peaceful Uses of Atomic Energy, Geneva September 1971, Vol. 11.
- IWM (1999): International Waste Management, Website des U.S. Department of Energy http://edt.pnl.gov:2080/fac/[france, netherlands, sweden]/factsheet.htlm.
- Jonas H. (1979): Das Prinzip Verantwortung, Insel Verlag, Frankfurt a. M.
- Kreuzer, K. (1992): Ein Hüte-Konzept für radioaktive Abfälle, neue Wege, März 1992, 86-Jahrgang, Nr. 3.
- MacLean, D. (1986): ed., Values at Risk, Totowa NJ, Rowman and Allanheld.
- Moore, G. E. (1951): Principia Ethica, Cambridge, Cambridge University Press.
- nagra (1988): Sedimentstudie – Zwischenbericht 1988, Möglichkeiten zur Endlagerung radioaktiver Abfälle in den Sedimenten der Schweiz. NTB 88-25.
- nagra (1994a): Sedimentstudie, Zwischenbericht 1993. NTB 94-10.
- nagra (1994b): Model Radioactive Waste Inventory for Swiss Waste Disposal Projects. NTB 93-21.
- nagra (1997): 25 Jahre nagra. nagra Wettingen.
- nagra (1998): Endlager für schwach- und mittelaktive Abfälle am Standort Wellenberg. Etappen auf dem Wege zum Verschluss; präzisierende Darstellung der Kontrollierbarkeit und Rückholbarkeit, NTB 98-04.
- nagra (1999): Start der Langzeitmessungen in der Bohrung Benken (ZH). Pressemitteilung vom 16. Juli 1999.
- NEA (1995): Nuclear Energy Agency – OECD, The Environmental and Ethical Basis of Geological Disposal. A Collective Opinion of the NEA Radioactive Waste Management Committee, Paris.
- NEA (1997a): Nuclear Energy Agency – OECD, Regulating the Long-Term Safety of Radioactive Waste Disposal. - Proceedings of a NEA International Workshop, Cordoba, Spain, 20-23 January 1997, Paris.
- NEA (1997b): Nuclear Energy Agency – OECD, Update on Waste Management Policies and Programmes. Nuclear Waste Bulletin No. 12, Paris.

- NEA (1998): Nuclear Energy Agency – OECD, Update on Waste Management Policies and Programmes. Nuclear Waste Bulletin, 13, Paris.
- NEA (1999): Nuclear Energy Agency - OECD, Proceedings of the Fifth OECD/NEA Information Exchange Meeting on Actinide and Fission Product Partitioning and Transmutation, 25-27 November 1998, Mol, Belgium. Paris.
- NL (1993): The Position of the Dutch Government on Deep Burial. - In: Niedersächsisches Umweltministerium (Hrsg.): Endlager-Hearing Braunschweig. Tagungsband II, S. 374-379, Hannover (Internationales Endlager-Hearing 21.-23. September 1993).
- Nux (1991): The Nuclear Guardianship Project, nux oct. 1990.
- OCRWM (1998): U.S. Department of Energy, Office of Civilian Radioactive Waste Management (1998): Civilian Radioactive Waste Management Program Plan. Revision 2.- 53 S., Washington DC.
- Parfit, D. (1983): Energy policy and the further future: the social discount rate, in Energy and the Future, D. MacLean and P. Brown, eds. Totowa NJ, Rowman and Allanheld.
- Richardson, P. J. (1999): Development of Retrievability Plans, Ashby de la Zouch (UK), March 1999, on behalf of the state coordinator for radioactive waste disposal of the Swedish Ministry of the Environment.
- Roseboom (1983): The case for retrievable high-level nuclear waste-disposal, Fifth International Conference on High-Level Radioactive Waste Management, Las Vegas, Vol. 3.
- Ruh, H. (1998): Energie-Dialog Entsorgung, Schlussbericht des Vorsitzenden zu Handen des Eidgenössischen Departements für Umwelt, Verkehr, Energie und Kommunukation. Bundesamt für Energie, Bern.
- Selling, H. et al. (1998): A Retrievable Concept for an Underground Radioactive Waste Repository in the Netherlands.- In: HLW, LLW, Mixed Wastes and Environmental Restauration: Working towards a Cleaner Environment. Proceedings of WM '98, 1.-5.3.1998, Tucson, Arizona.
- SES/Greenpeace (1998): Radioaktive Abfälle: Handlungsperspektiven. In Ruh (1998).
- SES (1999): Atomalptraum ohne Ende? Das Magazin der Schweizerischen Energie-Stiftung SES, Nr. 4.
- Shrader-Frechette, K. (1993): Burying Uncertainty: Risk and the Case against Geological Disposal of Nuclear Waste, Berkeley, University of California Press.
- SKB (1999): Svensk Kärnbränslehantering AB, Activities 1998, Stockholm.
- SKI (1999): Swedish Nuclear Power Inspectorate, The Swedish Nuclear Power Inspectorate's Evaluation of SKB's RD & D Program 1998. Summary and Conclusions. SKI Report, 99:30, Stockholm.
- Slovic (1991): Slovic, P., Flynn, J. H., Layman, M., Perceived Risk, Trust and the Politics of Nuclear Science , Science, vol. 254, p. 1603-1607, 13 Dec. 1991.
- TAG (1998): Technische Arbeitsgruppe Wellenberg, Endlager für schwach- und mittelradioaktive Abfälle: Stellungnahme zu technischen Aspekten des Projektes Wellenberg. Bundesamt für Energie, Bern.
- Taylor Ch. (1992): Sources of the self: the making of the modern identity, Cambridge University Press, Cambridge.
- Walzer M. (1983): Spheres of Justice. A Defense of Pluralism and Equality, Blackwell, Oxford.

- Wegmüller M. & Chabot J.D. (1997): Einflüsse des Bergwassers auf die Dauerhaftigkeit von Bauwerken. Schlussbericht 1997, IBB Forschungsprojekt 085/93, Institut für Bauplanung und Baubetrieb, ETH Zürich, Juli 1997
- ZWILAG (1994): Sicherheitsbericht zum Gesuch um Erteilung der nuklearen Bau- und Betriebsbewilligung für das Zentrale Zwischenlager Würenlingen, September 1994.
- ZWILAG (1997): Final Safety Analysis Report FSAR zum Gesuch um die Erteilung der Nuklearen Betriebsbewilligung für die ZWILAG-Behandlungsanlagen, Dezember 1997.

Comments relating to chapter 3

1. There is presently a diversity of theories on fairness. The ones discussed here are different models for fairness of distribution (how are resources and burdens to be divided between different generations and different social groups?), theories which are based on discussion or argumentation (how can the interests of future generations best be represented today?) and theories which refuse to compare prosperity with more fundamental values such as the intactness of nature, protection of the environment, etc.
2. We restrict our consideration to these two approaches because they are the most mature in terms of their arguments and have the strongest presence in social discussion (Damveld & Van den Berg 1999a).
3. How long the democratic institutions of Switzerland can be relied on is an open question. More than 500 years?
4. The type of management strategy relates to the lifetime of the radioactive waste. This principle can readily be demonstrated by the following example: According to the U.S. Department of Energy and the American National Academy of Science, it is not sufficient to demonstrate a minimum 500-year integrity for certain steel containers when the lifetime of the waste contained in them exceeds 10,000 years (cf. Shrader-Frechette 1993).
5. Solutions which allow for checking safety obviously reach their limits when they come to stand in the way of safety itself!
6. OECD, Recommendation of the Council on Guiding Principles Concerning International Economic Aspects of Environmental Policies, 26. May 1972. An overview of OECD texts on the 'producer (polluter) pays' principle can be found in OECD, Le Principe Pollueur-Payeur, Monographie sur l'environnement, Paris, 1992.

Appendix 1: Explanation of terminology

Anthropology	The science of man (conception of man, meaning of human existence, world-view).
Barriers	Barriers form the passive safety system in a disposal facility for protection of man and the environment. They consist of engineered and natural (geological) containment and retention systems which isolate the waste from the biosphere based on the multibarrier concept. The *engineered barriers* comprise the waste form (e.g. glass), the packaging of the waste (e.g. steel containers) and the backfilling of caverns and tunnels (e.g. with bentonite). The *natural barriers* are the host rock in the disposal zone and the rest of the geosphere (host rock and further geological environment). Besides their retention function, the natural barriers provide long-term protection of the engineered barriers.
Communitarianism	Political-philosophical way of thought which lays weight on the community (e.g. family, language groups, religious groups, population groups, cultural groups) in which values are distributed. Outside these groups, the values which are observed are not necessarily the same. It is not possible to say anything which is ethically generally binding beyond the limits of the group, except that the group and its values have to be defended (opposite: universalism).
Contractual approach	Ethical approach which determines fairness by mutual agreement (contracts, agreements, democratic decisions). Proponents of contractualism include Rousseau and Rawls.
Deep disposal facility	A facility in deep geological formations for interim storage, indefinite storage or long-term storage, or a repository.
Deontological approach	Deontology: from dein (gr.) *to be necessary*. Normative, ethical approach inspired by Kant dealing with self-imposed duties. It seeks what is just or fair not in relation to content but via formal procedures.
Discounting	Annual percentage used to weight a future value (cost or benefit) in order to determine its present value. *Discounting* is thus the opposite of an interest rate, which is an annual percentage used to weight a present value in order to determine its future worth. In economics, interest is seen as positive and *discounting* as negative. With an annual *discounting* of 10%, the effect on the well-being of people in 20 years is valued at only a tenth of the effect today.
Disposal zone	Zone, including safety reserves (e.g. distance to surrounding rock), identified for layout of the underground structures for emplacement of radioactive waste.
Entsorgungsnachweis (demonstration of feasibility of HLW disposal)	Demonstration, based on scientific and technical investigations, that safe management of HLW is feasible in Switzerland. Based on the decision of the Federal Council of 3rd June 1988 on Project Gewähr, the Entsorgungsnachweis for HLW consists of three components, namely a safety demonstration (→), a siting demonstration (→) and a feasibility demonstration (→).
Feasibility demonstration (HLW disposal)	The feasibility demonstration has to show that a repository can be constructed, operated and safely closed in the selected host rock to meet all the safety requirements and with the technology available today.

Geological repository	Facility for long-term, maintenance-free, indefinite isolation of radioactive waste without the intention of retrieval. The repository is located in deep geological formations of the earth's crust. The long-term protection of man and the environment after closure is ensured only by the barriers (→).
Geosphere	The term includes all the geological units between the waste emplacement zones and the biosphere (including the host rock).
Guardianship concept	As an extreme example of indefinite storage (→) the guardianship concept foresees indefinite storage of the waste under human supervision, for example by a form of a nuclear priesthood in cathedral- or pyramid-like structures at the earth's surface.
Host rock	The host rock is that part of the geosphere which protects the engineered barriers, restricts water flow to the facility and retains radionuclides. The disposal facility is located in the host rock.
Indefinite storage facility	Facility for indefinite storage of radioactive waste. Protection of man and the environment is based on engineered barriers (→) and measures (→) with no time restriction.
Interim storage facility	Facility for short- to medium-term storage of waste packages in purpose-built halls with the intention of later removal.
Long-term safety	The long-term protection of man and the environment by barriers (→) and/or measures (→).
Measures	Measures are the active safety system of a disposal facility which ensure the protection of man and the environment. They include technical, organisational and administrative activities such as maintenance, repair, control and monitoring of the facility and the emplaced waste, as well as possible retrieval (→).
Near-field	The near-field is that part of the host rock which is affected by the construction and the presence of the structures of the disposal facility (rock destressing, changes in chemical conditions, etc.).
Neo-Aristotelism	Communitarianism (→) is a neo-Aristotelian way of thought. As in the case of Aristotle, the accent is on the common good. Virtues (as opposed to duties) are particularly important.
Pluralistic society	A society in which different views of goodness and fairness exist side by side, without a third "neutral" standpoint from which it can be decided which views are better, fairer or worse.
Relativism	Relativism deduces from the fact of pluralism that every view/opinion is of equal value and draws the conclusion that no view is really meaningful.
Retrievability	Retrievability is the possibility to remove waste from an open, partly or completely closed facility with more or less large technical or financial investment.
Retrieval	Retrieval is the desired removal of radioactive waste from a facility with the aim of further disposal, processing or re-use.
Reversibility	Reversibility of actions is made up of a combination of system properties and measures (→) which ensure decisions and activities which have already been carried out can be made retroactive.
Safety demonstration (HLW disposal)	The safety demonstration has to show that the long-term safety of a repository can be assured in the defined host rock with geological and hydrogeological properties as found in exploration programmes and with the selected engineered barriers.

Safety systems	Barriers (→) and measures (→) which offer protection against unforeseen natural or technical events and thus prevent unacceptable hazards to man and the environment.
Security	Installations and measures against unauthorised actions of third parties which could compromise the safety systems (→).
Seismic investigations	Seismic investigations involve generating artificial oscillations at the earth's surface. These migrate in the form of waves deep into the underground and are reflected by individual rock layers. The reflected waves are registered at the surface and allow spatial imaging of geological structures.
Siting demonstration (HLW disposal)	Based on documented investigation results, the siting demonstration has to show that a sufficiently large body of rock exists with the properties specified in the safety demonstration, such that implementation of a repository in the selected siting region can be initiated with a view to success.
Subjectivism	Ethical approach according to which the (ethical) truth can be determined only on the level of the human subject (as opposed to universalism).
Surface disposal facility	A facility at the earth's surface for interim, indefinite or long-term storage, or a surface repository.
Teleological ethics	Ethics which define good in relation to an objective (Telos). This good can be happiness, utilitarianism, fairness or the common good. Teleology gives content to this good and considers which means can be used to achieve this objective (opposite: deontology, procedural ethics).
Toxicity	Harmfulness of a substance when taken into the body. In the case of radiotoxicity, the damage is due to the nuclide-specific effect of radiation. The radiotoxicity of a waste package or a disposal facility is the sum of the toxicities of all contained nuclides.
Transcendence	Theory according to which eternal ideas, truths, substances or the actual "thing in itself" exist behind transient things which can be perceived by the senses.
Transcendental concept	Concept or view which claims a transcendence.
Transmutation	Deliberate transformation of radioisotopes with long half-lives into stable isotopes or radioisotopes with short half-lives by bombardment with neutrons or charged particles. Before this, the radioisotopes have to be separated in costly (technical and financial) procedures.
Utilitarianism	A teleological ethical approach which seeks the largest possible good for the maximum number of people as an objective.

Appendix 2: Abbreviations

BFE	Federal Office of Energy
DL	Indefinite storage facility, indefinite storage
EKRA	Expert Group on Disposal Concepts for Radioactive Waste
GEL	Geological repository, geological disposal
GNW	Genossenschaft für Nukleare Entsorgung Wellenberg
HLW	High-level waste
HSK	Swiss Federal Nuclear Safety Inspectorate
ILW	Intermediate-level waste
KEG	Nuclear energy law (in preparation)
KGL	Monitored long-term geological disposal facility, monitored long-term geological disposal
L/ILW	Low- and intermediate-level waste
LLW	Low-level waste
LZL	Long-term storage facility, long-term storage
MIR	Medicine, industry and research
MNA	Komitee für die Mitsprache der Nidwaldner Bevölkerung bei Atomanlagen
MOX	Mixed oxide fuel elements
nagra	National Cooperative for the Disposal of Radioactive Waste
NPP	Nuclear power plant(s)
ODL	Indefinite surface storage
OEL	Surface disposal
OLZL	Long-term surface storage
PSI	Paul Scherrer Institute
SES	Swiss Energy Foundation
TDL	Indefinite deep storage
TRU	Long-lived intermediate-level waste
UVEK	Federal Department for the Environment, Transport, Energy and Communication
ZWILAG	Centralised interim storage facility (Würenlingen)

Appendix 3: Nuclear waste management in Switzerland - key dates

1957	Constitutional article on atomic energy
1959	Federal Atomic Law on the peaceful use of nuclear energy and radiation protection
1969	Start of operation of the first NPP (Beznau I)
1972	Founding of nagra
1978	Federal Government Act on the Atomic Law: producer pays principle, requirement for "Gewähr" (feasibility study) nagra: First concept for nuclear waste management in Switzerland
1980	nagra: Submission of 12 applications for exploratory boreholes in Northern Switzerland (crystalline, HLW programme)
1982	Last deep sea dumping of Swiss low- and intermediate-level waste Federal Council: Permits granted for boreholes in crystalline nagra: Borehole programme up to 1989
1983	nagra: Application for exploration permits for 3 sites for a L/ILW repository (TI, UR, VD)
1985	nagra: Submission of "Project Gewähr" Federal Council: Permit for investigations at three L/ILW sites (without exploratory drift)
1987	nagra: Submission of exploration request for Wellenberg (NW)
1988	Federal Council: Decision on "Gewähr" L/ILW: Demonstration of feasibility fulfilled HLW/TRU: Safety demonstration fulfilled, siting demonstration not fulfilled, no reservations regarding engineering Federal Council: Permit for part of the exploration programme at Wellenberg nagra: Investigations at Wellenberg up to 1995
1989	Ordinance on preparatory measures
1990	ZWILAG: Submission of general licence application for an interim storage facility Action programme "Energy 2000", waste management conference
1992	EVED[6]: Establishment of a working group with representatives of the Federal Government and the four potential siting Cantons for a L/ILW repository (NW, TI, UR, VD) Establishment of a group to resolve conflict on radwaste issues, terminated early because of the retreat of the environmental organisations following the Mühleberg decision (extension of operating permit)
1993	Federal Council: General licence for ZWILAG Conclusions of the working group consisting of the Federal Government and four potential siting Cantons for a L/ILW repository: information is available to allow a decision on site selection to be made nagra: Wellenberg should be pursued with top priority as a L/ILW site
1994	nagra: Submission of general licence application for Wellenberg nagra: Submission of exploration request for Leuggern/Böttstein and Benken Parliament approves general licence for ZWILAG
1995	Canton Nidwalden: Rejection of Wellenberg applications in a referendum: Recommendation of Cantonal Government on general licence application: 51.9% no to 48.1% yes Concession for use of underground: 52.5% no to 47.5% yes
1996	Federal Council: Permit for Benken borehole (HLW programme) Federal Council: Construction and partial operating licence for ZWILAG
1997	EVED: Suspension of general licence application for Wellenberg Establishment of Wellenberg working groups (technical and economic aspects)
1998	UVEK: Energy Dialogue on waste management, no consensus, Ruh report Publication of results of Wellenberg working groups
1999	Federal Councillors Leuenberger und Couchepin discuss with siting Cantons, NPP operators and environmental organisations on the operating lifetime of the existing NPPs and solution to the waste management problem UVEK: Establishment of EKRA

[6] Since 1.1.1998: UVEK.

Appendix 4: Laws, ordinances and guidelines relating to radioactive waste management

Laws

- Federal Law on the Peaceful Use of Nuclear Energy (the Atomic Act) of 23rd December 1959 (*SR 732.0*)
- Federal Government Act on the Atomic Law of 6th October 1978 (*SR 732.01*)
- Nuclear Energy Liability Law of 18th March 1983 (*SR 732.44*)
- Radiological Protection Law of 22nd March 1991 (*SR 814.5*0)

Ordinances

- Ordinance on Definition of Terminology and Licences in the Field of Atomic Energy (Atomic Regulation) of 18th January 1984 (*SR 732.11*)
- Ordinance on Deliverable Radioactive Waste of 8th July 1996 (*SR 814.557*)
- Ordinance on Preparatory Measures with Respect to Construction of a Repository for Radioactive Waste of 27th November 1989 (*SR 732.012*)
- Ordinance on the Decommissioning Fund for Nuclear Facilities of 5th December 1983 (*SR 732.013*)
- Nuclear Energy Liability Ordinance of 5th December 1983 (*SR 732. 44*)
- Radiological Protection Ordinance of 22nd June 1994 (*SR 814.501*)

International Conventions

- Convention of 29th December 1972 on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, ratified in 1979 (*SR 0.814.287*)
- Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management

HSK Guidelines

- HSK-R-14 Conditioning and Interim Storage of Radioactive Waste, December 1988
- HSK-R-21: Protection Objectives for the Disposal of Radioactive Waste, November 1993

Recommendations of the IAEA (International Atomic Energy Agency), Vienna

- The Principles of Radioactive Waste Management. Safety series N° 111-F, 1995
- Establishing a National System for Radioactive Waste Management. Safety series N° 111-S-1, 1995