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Low-Level Radioactive Waste Repositories: An Analysis of Costs

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LOW-LEVEL RADIOACTIVE WASTE REPOSITORIES

An Analysis of Costs

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– *developing exchanges of scientific and technical information particularly through participation in common services;*
– *setting up international research and development programmes and joint undertakings.*

In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has concluded a Co-operation Agreement, as well as with other international organisations in the nuclear field.

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DÉPÔTS DE DÉCHETS RADIOACTIFS DE FAIBLE ACTIVITÉ
Une analyse des coûts

FOREWORD

Low-level radioactive wastes are those that do not have a particularly long life nor produce a great deal of heat while decaying. Therefore, they are not as difficult to manage as spent nuclear fuel, radioactive waste separated at reprocessing plants or other high-level radioactive waste. Nevertheless, they do require specially engineered containers and disposal facilities so that their disposal does not breach norms for the protection of people and the environment. The bulk of these wastes arise in the normal operation of nuclear power plants and the associated fuel cycle facilities. In most OECD countries, there are also significant arisings of low-level radioactive waste from the use of radioactive isotopes in medicine, industry and agriculture.

One of the objectives of the Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC) is to provide up-to-date information on the economics of all steps of the nuclear fuel cycle. In this context, the cost of low-level waste disposal is of interest to the Committee and an expert group was convened to collect and review cost information available from a number of operating repositories, as well as cost estimates for repository projects.

The report shows that those costs are low relative to the overall revenues and costs of nuclear electricity generation. In absolute terms, however, the costs of repositories for low-level waste are high enough to justify seeking ways and means of reducing them. The study explored whether the experience acquired through building and operating low-level waste repositories could be used to reduce the costs of future repositories.

The report is published on the responsibility of the Secretary-General of the OECD. It reflects the collective views of the expert group, though not necessarily the views of the participating countries or international organisations.

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EXECUTIVE SUMMARY

The Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC) has conducted a number of studies on the costs of radioactive waste management. The reports *Decommissioning of Nuclear Facilities (*1991*)* and *The Cost of High-Level Waste Disposal in Geological Repositories (*1992*)* are two examples. This new study on the costs of low-level radioactive waste repositories complements these previous studies, and completes the assessment of the costs of radioactive waste management.

In some NEA Member countries, repositories for low and intermediate-level wastes (hereafter, referred to as LLW) have been operated for a considerable period, and other countries are planning to have repositories in the near future. All of them are built and operated or planned in accordance with stringent national safety regulations that conform with internationally accepted standards. The types, sizes and geological conditions of the repositories may be quite different from one country to another. Although the cost of LLW disposal is thought to be a small part of the total cost of nuclear power generation, the absolute costs of investment in and operation of repositories, together with the potential requirements for long-term monitoring after closure, are by no means small. This study on the analysis of the cost elements such as planning and licensing, civil construction, operation and closure is also intended to show effective means of managing LLW repositories and ways of reducing their costs while ensuring the highest level of safety.

Scope of the study

The scope of the analysis includes LLW repositories in operation or planned in NEA Member countries. The primary focus of the study is near-surface repositories, such as the Centre de l'Aube in France or Drigg in the United Kingdom, and cavern-based repositories, such as SFR in Sweden. Geological repositories dedicated to high-level waste (HLW) have been excluded.

Cost elements considered in the study are: planning and licensing costs; design and construction costs; operation costs; decommissioning and closure costs; and costs of post-closure activities. Costs that are typically incurred outside the repositories such as waste treatment, conditioning, packaging and interim storage are not included. Economic incentives related to repository siting are mentioned in some cases where available.

Overview of LLW repositories in Member countries

Management practices for the disposal of LLW include three main options:

- near-surface disposal;
- disposal in caverns at intermediate depth;
- disposal in deep geological formations.

The choice of a particular disposal system to achieve international safety objectives and national regulatory requirements depends on the type of waste (e.g. physical form, radioactive content) and local conditions, including site characteristics and socio-political considerations. Increasingly, reliance is placed on the adoption of a multi-barrier approach in which the waste form, engineered barriers and finally the site itself contribute to the isolation of the waste from the environment for timescales adequate for its decay to insignificant activity levels.

The study was based on cost data for 19 repositories. The repositories considered in the study are listed in the following table. Several countries have plans for repositories which are sufficiently advanced that it was possible to include their cost estimates in the study.

Low and intermediate-level radioactive waste repositories in NEA Member countries

Country	Near-Surface	Cavern-Based	Year operation started
Australia	√		1992, and planned
Belgium	√		Planned
Canada	√		Planned
Czech Republic	√	√	1964, 1974, 1994
Finland		√	1992, 1998
France	√		1969, 1992
Germany		√	1978, and planned
Hungary	√		1977, and planned
Italy			Planned
Japan	√		1992
Korea		√	Planned/cancelled*
Spain	√		1993
Sweden		√	1988
Switzerland		√	Planned
United Kingdom	√		1959

* Although the project has been cancelled, cost elements were provided for the study.

Limitation of the analysis

The aim of the report is not to show which repository has the lowest or highest costs, but rather to present factors affecting LLW repository costs. Direct cost comparisons among countries that have different nuclear development programmes are not relevant. Factors such as size of programme, timing and exchange rate make costs not directly comparable. In addition, as shown throughout the study, different technical and non-technical features of the repositories also contribute to making direct comparisons meaningless.

Repositories meet widely different requirements in terms of waste definition and the range of waste types accepted. Some repositories only accept low-level waste whereas others accept intermediate-level waste as well, and the definitions of waste categories differ. The origin of waste varies from medical uses to nuclear fuel cycle activities including power generation, decommissioning and fuel reprocessing. This variation leads to uniformity of waste as compared with high-level waste. These factors, though all of them are not analysed in detail in the report, affect the comparability of repository costs among countries.

Factors affecting LLW disposal cost

The study carefully examined LLW disposal cost elements and a number of observations have resulted from the analysis. Major findings are:

- Planning and licensing costs could be a significant portion of the whole cost. The German and Swiss cases showed fairly large costs for planning and licensing. This might be attributed to socio-political factors in those countries, but this could not be quantified. The general upward trend of these costs implies further increases in the planning costs for future repositories.
- A scale effect has been found in particular in construction costs of near-surface repositories. Unit construction cost, i.e. total construction cost divided by volume capacity of the repository, has been found to be lower for repositories with larger capacities. This is to be expected as much of the total construction cost is associated with facilities and infrastructures which are largely independent of the size of the repositories.
- The construction cost of near-surface repositories is generally lower than that of cavern-type repositories, but a specific ratio cannot be derived since there are large cost differences between individual facilities for a variety of reasons. This general observation is specifically confirmed in the case of two planned repositories in Hungary. A simple comparison between costs of near-surface, vault-type repositories and cavern-type repositories should be avoided as they have different structures.
- The costs of those repositories which are adjacent to existing facilities, as is the case in Sweden and Finland, are lower than those of other repositories due to cost sharing.
- Operating costs are not affected by size to the same extent as construction costs although, again, certain parts of the operating costs such as those for administration, security and radioactivity monitoring are fixed, i.e. not proportional to the volume of annual delivery of waste.
- Since the repositories in Member countries have not yet experienced a complete closure process, the cost of closing the repositories could not be analysed comprehensively in the study. Some countries have given their estimated cost of closure. France effectively “capped” the Centre de la Manche repository in 1995, but detailed figures are not yet available. No real experience has been gained yet on the institutional control period.

LLW repository costs, as defined in this study, appear to be a small fraction of total electricity generation costs. The costs presented in the report have not been discounted, and it should be noted that discounting would further reduce their impact. Even undiscounted costs have been found to be a very small fraction of the total electricity generation cost. Total costs, undiscounted and obtained by simple summation of cost elements, range from 0.02 to 0.17 US mills per kilowatt hour. An illustrative sample calculation that takes discounting into account confirms the small impact of LLW disposal costs on generation costs.

Finally, other cost components such as sorting, treatment, conditioning and transport that were not considered in this study are not negligible. These cost elements are part of the true cost in overall low-level radioactive waste management. They have not been studied since the waste repository is the main focus of the report, and these activities are generally not undertaken at the repository. An overall waste management cost study which may well incorporate costs related to high-level waste and decommissioning waste management, would be of value as a follow-up to this study.

1. INTRODUCTION

1.1 Background and objectives of the study

In some NEA Member countries repositories for low and intermediate-level waste have been operated for a considerable period and these cover a range of types, sizes and geological conditions, the design being influenced by socio-political factors as well as technical and regulatory requirements. Although the cost of LLW disposal is considered to be a fairly small part of the total cost of nuclear power generation, the absolute costs of establishing, operating and closing repositories together with the costs of possible long-term monitoring after closure are by no means small.

The overall objective of the study is to provide Member countries with comprehensive and authoritative information on the costs of LLW repositories based upon experiences and design studies. The study aims at: providing basic cost information for low-level waste repositories in NEA Member countries; analysing those factors which affect the cost elements of the repositories; showing LLW repository cost as a proportion of total nuclear electricity generation cost; and providing insights into ways and means to achieve more efficient and more cost effective management of LLW repositories. As regards the third aim, cost estimates are presented in aggregate forms such as LLW repository cost per unit of electricity generated showing that LLW disposal costs are a small fraction of total generation costs.

1.2 Scope of the study

The study deals with repositories for low and intermediate-level waste in operation or planned in NEA Member countries and therefore, also includes facilities in countries without nuclear power programmes. Recognising that waste categories may, and often do, differ from country to country, the study does not define a radioactivity threshold level for LLW. Instead, this report provides information on the waste classification prevailing in each country in order to facilitate compilation and clarification of the data collected. In this regard, intermediate-level waste (ILW) is also included in the study as it is often the case that LLW and ILW are disposed at the same repository.

The primary focus of the study is near-surface repositories, such as the Centre de l'Aube in France or Drigg in the United Kingdom and cavern-based repositories, such as SFR in Sweden. Deeper geological facilities such as the Swiss repository which is intended to accept waste are also included. Geological repositories dedicated to high-level waste (HLW), i.e. spent fuel and/or reprocessing waste, have been excluded.

A waste management sequence typically includes sorting by categories, treatment (volume reduction, decontamination, incineration), conditioning (immobilisation into a matrix), transport, interim storage pending disposal, and final disposal.[1] Among these activities, the study focuses on final disposal and analyses the costs of the LLW repository, including planning, construction, operation, closure and post-closure monitoring where relevant. It does not cover associated financial liability issues such as funding schemes and financial charges for the investment, which have already been studied in another NEA publication.[2] The costs of sorting, treatment, conditioning, transport and interim storage of LLW are not covered in the study, since these processes are quite often carried out by the waste generator prior to dispatch to the repository.

Although the study focuses mainly on LLW from the electricity sector, the waste arising from other nuclear activities such as research and development, medical and industrial usage of radioisotopes are included.

1.3 Methodology used and structure of the report

This study was undertaken under the auspices of the NEA's Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC). An expert group with members from thirteen countries and two international organisations was set up for the study. Five other NEA Member countries have provided their country's information by correspondence.

After establishing the expert group, the methodology used in the study was to distribute a set of questionnaires to the group members and also to NDC members of the five countries participating by correspondence. The expert group then discussed and analysed the data collected through the questionnaires and sought additional information through a further questionnaire. Further analysis and drafting of the report was accomplished by a small drafting group for review and agreement of a final report by the expert group. The material in the report is therefore essentially based on the country information provided through the questionnaire.

The structure of the report is as follows:

- Chapter 2 gives a brief description of the different types of repositories to show technical features which can help an analysis in the following chapters. This chapter also reviews general information about member country policies and regulations on LLW disposal, and includes in summary form, basic facts and data on LLW repositories. Further country specific details are given in Annex 2.

- Chapter 3 provides assumptions used in the analysis, defines the cost elements, describes the methodology used in the study and highlights the financial and accounting issues involved in the cost calculation. It also touches on gaps and inconsistencies in the data.

- Chapters 4 and 5 analyse the data. Chapter 4 compares the available data and describes a number of factors, both technical and non-technical, which affect each element of the cost. Chapter 5 provides a hypothetical sample calculation to show the significance of the LLW repository cost in relation to the total cost of nuclear electricity generation.

1.4 Other related studies

Radioactive waste management includes various categories of waste, i.e. high-level waste arising from spent fuel and reprocessing, intermediate and low-level waste from operation and maintenance of nuclear facilities, and low-level waste from decommissioning the facilities. Since this study does not cover HLW nor, in most cases, decommissioning wastes, the readers are invited to refer to other publications for further comprehensive analysis. A bibliography is given at the end of the report.

2. LOW-LEVEL RADIOACTIVE WASTE MANAGEMENT SYSTEM

2.1 Repository concept

2.1.1 Introduction

The objective of radioactive waste management is to collect, handle, treat, condition, store, transport and dispose of radioactive waste in a manner that protects human health and the environment, without imposing undue burdens on future generations. In pursuit of this objective the IAEA has developed a set of fundamental safety principles for waste disposal[3] which have international acceptance. These principles have subsequently been supported by safety standards and safety guides.

The choice of a particular disposal system to achieve the international safety objectives for disposal of radioactive waste depends on the waste type (e.g. physical form, radioactive content) and also local conditions, including site characteristics and considerations of socio-political acceptance. Increasingly, reliance is placed on the adoption of a multi-barrier approach[3,4] where the wasteform, engineered barriers and finally the site itself all contribute to the isolation of the waste from the environment for timescales consistent with its decay to insignificant levels.

Management practices for the disposal of LLW and ILW (adopted or under consideration) encompass three main options which are:

- near-surface disposal;
- disposal in caverns at intermediate depth;
- disposal in deep geological formations.

The major disposal options are described below.

2.1.2 Near-surface disposal

The IAEA Safety Guide[5] on the classification of radioactive waste also considers disposal options and recommends simple surface landfills and engineered surface facilities as near-surface disposal methods for short-lived low and intermediate-level waste.

The Guide includes disposals in caverns at depths of a few tens of metres as near-surface disposal but for the purposes of this study such disposals are discussed separately in Section 2.1.3.

Simple surface landfills

Near-surface disposal in unlined trenches or pits is a disposal option practised in a number of countries. This option implies that waste to be disposed contains short-lived radionuclides of low or medium specific activity with only very low amounts of long-lived radionuclides (categories IV and V of the IAEA classification).

Protection of the environment is therefore achieved through a combination of climate, waste conditioning and packaging requirements; typically trenches are located above the groundwater level and frequently on a layer of low permeability material which has good retention characteristics for most radionuclides present in the waste.

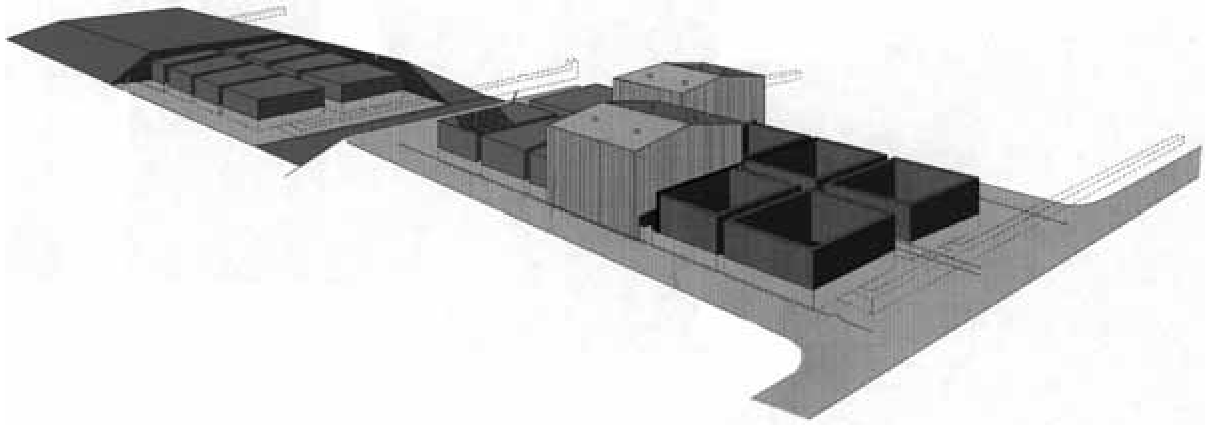
Near-surface disposal with engineered barriers

Such systems incorporate a number of engineered barriers to limit or delay nuclide migration from the repository. Ideally, selection of the site itself contributes to the overall effectiveness of the disposal system. Use of the multi-barrier system brings benefits in that waste not acceptable for disposal in a simple trench may be acceptable in a near-surface repository with a multi-barrier system.

Many near-surface repositories in operation or in the design phase are equipped with engineered barriers and drainage systems for control of water infiltration, to meet safety regulations or to offer more flexibility for waste packaging. Typically the disposal units are lined with concrete, bitumen or other materials to improve isolation of the waste. The space between the waste packages is often filled with soil, clay or concrete grout. Low permeability covers are added to the filled disposal unit to minimise the percolation of surface water into the waste. Water diversion and drainage systems are used to divert water away from the disposal units.

The disposal units are usually located above the water table. In some countries, however, the local conditions require that the disposal vaults be constructed below the water table. The latter option calls for use of materials with low permeability to ensure low penetration of water into the disposal area and additional measures to control water infiltration.

Figure 2.1 **Engineered near-surface repository (El Cabril, Spain)**



2.1.3 *Disposal in caverns at intermediate depth (cavern-based repository)*

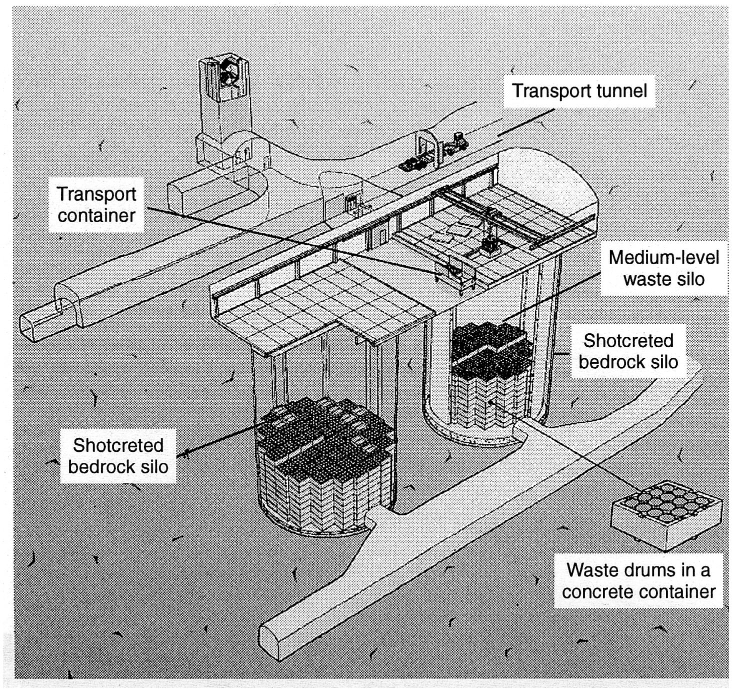
The primary distinguishing feature of sub-surface concepts as compared to near-surface concepts is that the distance below the ground surface is usually adequate to essentially eliminate concerns of intrusion by plants, animals and humans. The sub-surface disposal concept normally implies disposal at a depth of tens of metres and a variety of different caverns located in different geological environments have been used for different types of waste. Typically these caverns may be classified as specially excavated cavities and disused mines.

Where the cavities are specially excavated then a variety of shapes and volumes have been employed which have been influenced by the planned disposal methods, the waste type and quantity and, of course, the geometry of the host formation. The repository can include tunnels, vaults, vertical or horizontal caverns or some combination of these.

Sub-surface repositories can in general accept a wider range of radioactive wastes including, for example, IAEA categories II and III (long-lived ILW and LLW). Socio-political considerations in certain countries also dictate that low and even very low-level decommissioning waste is disposed of in sub-surface caverns. In certain cases the various waste types are disposed of in separate sections, galleries or vaults.

The inherent safety of geological isolation in a suitable host rock may be enhanced further by adding other barriers, for example, the waste conditioning and packaging, overpacking materials for the waste containers, buffer and backfill materials and other engineered structures.

Figure 2.2 **Cavern-based repository (Olkiluoto, Finland)**

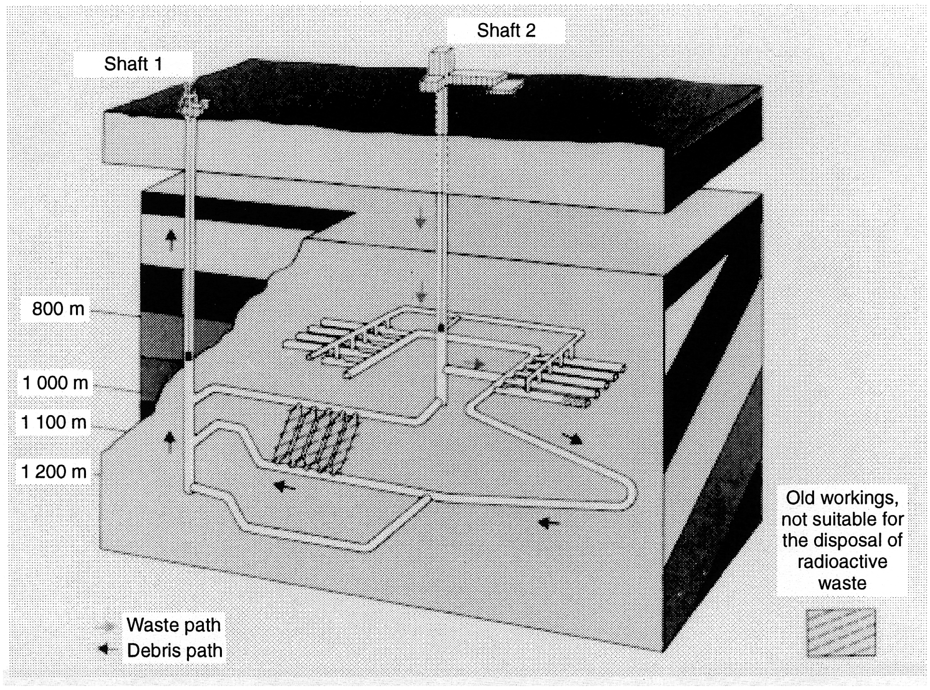


2.1.4 Geological disposal

The geological disposal of radioactive waste is generally considered the required approach for high level and alpha-bearing wastes where it is deemed necessary to isolate these in deep geological formations, that is at depths of at least a few hundred metres.

In certain countries, again on socio-political grounds, deep geological disposal is required for all types of radioactive waste.

Figure 2.3 **Geological repository (Konrad – planned – Germany)**



2.1.5 Institutional control after closure

Institutional controls placed on disposal facilities after their closure contribute to the enhancement of safety, especially in the case of near-surface disposal facilities, as discussed in IAEA's publications.[4,5,6] During the institutional control period, active controls (such as restrictions on access, monitoring, surveillance or remedial action), or passive controls (such as restrictions on land use), or a combination of both may be applied. The duration and effectiveness of institutional controls is taken into account during safety assessment of the disposal facility. This study shows that most NEA countries have plans to apply institutional controls after the closure of near-surface disposal facilities and their durations range from 100 years to 300 years. Some countries have yet to decide on the duration and content of the institutional controls.

In the case of cavern-based repositories, which can contain significant quantities of long-lived radionuclides, it is nevertheless considered that institutional controls have a very limited contribution to make to the enhancement of safety, owing to the fact that it is unreasonable to rely on such measures over the extended time periods likely to be involved in the return of any activity to the biosphere.[7] However, institutional controls are not precluded for limited periods of time and in this study, a country has plans to apply institutional controls for 200 to 300 years after the closure of cavern-based facilities. Some countries consider that active institutional controls are not necessary for cavern-based repositories, while some have not yet made a decision on the institutional controls.

2.2 Overview of low-level radioactive waste disposal in NEA Member countries

In most NEA Member countries, disposal of LLW and ILW is already practised. Also, as LLW and ILW are generated from diverse sources such as nuclear power plants and radioisotopes using facilities, and contain a wide range of radionuclides, different types of classification and disposal methods are used according to national policies and strategies. This section gives a short description of the general situation regarding LLW disposal in NEA Member countries. Detailed information appears in Annex 2.

2.2.1 Policy, strategy and regulation of LLW disposal

Most countries have already established their own policies as well as the legal framework, detailed regulations and standards to ensure the safe disposal of LLW, based on the international safety criteria and standards developed by ICRP and IAEA. More than half of these countries have their own disposal facilities and others have actual or future plans to build repositories. It is noted that there is a tendency for the planning and site selection phase to be prolonged in the development of new disposal facilities as compared with that experienced for older repositories. This might be attributed to the fact that it has become more difficult to gain public confidence and acceptance because of safety concerns and siting aspects.

2.2.2 Owner/operator of disposal facility

Owners/operators of disposal facilities are mainly national agencies. Others are utilities, their affiliate companies or state-owned companies. Most countries have only one disposal organisation, but there are cases where more than one exist. Currently some countries also have plans to change laws in order to establish a new organisation, or to change the responsibilities, for disposal. It is not apparent that the type of ownership/operator influences the efficiency or the economics of the disposal activity. A further consideration, however, is that public organisations might have some merit in enhancing public confidence in the repository.

2.2.3 Waste origin and waste classification

LLW and ILW are mainly generated by the operation of nuclear power plants but also derive from medical and other uses of radioisotopes, research laboratories, etc. These diverse sources mean that the wastes have a wide range of chemical and physical properties, in addition to a wide range of radionuclides and radionuclide concentrations. As a result, the treatment and conditioning of these wastes for disposal can give rise to different forms and packages.

Classification of waste is a very important issue when considering disposal. Classification of radioactive waste assists in the identification of categories of waste acceptable at disposal facilities. A range of classification and disposal methods exist in NEA Member countries. Most countries have quantitative regulations to classify radioactive waste which can be accepted in disposal facilities. In these classifications, the concentration of radioactivity, maximum inventories of radioactivity and/or surface dose rates are specified. Radioactivity limits are defined for each radionuclide or for total radioactivity. However, there is a world-wide consensus on classification of radioactive waste into low, intermediate and high-level waste as proposed by the IAEA.[5]

2.3 Overview of LLW disposal in each country

2.3.1 Australia

Policy and strategy regarding radioactive waste disposal

Australia does not have a nuclear power industry. Australia is currently conducting a site selection study to identify a suitable site for a national repository for disposal of low and short-lived intermediate-level radioactive waste arising from research, industrial and medical use of radioisotopes. The Commonwealth Department of Primary Industries and Energy portfolio is responsible for establishing the repository and for radioactive waste policy within the Commonwealth. A new Commonwealth body, the Australian Radiation Protection and Nuclear Safety Agency will be responsible for regulating and licensing Commonwealth nuclear and radiation activities. The States have responsibility for management of radioactive waste produced within their jurisdiction. Western Australia (WA) has already established a final repository for its low-level radioactive waste. WA's Intractable Waste Disposal Facility (IWDF) includes a near-surface burial facility for LLW arising from medical, educational and research applications, by-products of mineral sands, mining ore samples, industrial isotope uses, and items withdrawn from service such as smoke detectors and luminescent "EXIT" signs. A variety of non-radioactive waste may also be disposed of by trench or shaft burial at the facility.

Regulation regarding waste categories and disposal

The National Health and Medical Research Council's (NHMRC) *Code of Practice for the Near-surface Disposal of Radioactive Waste in Australia* (NHMRC 1992) provides guidelines for the safe siting, design and operation of a near-surface disposal facility. The NHMRC Code defines four categories of radioactive waste for disposal and management purposes. Waste suitable for near-surface disposal is separated into categories A, B and C. The Code provides generic activity concentration limits for each category of waste. A fourth category, S, describes waste that is not suitable for shallow ground burial. The NHMRC has also developed a Code of Practice for the Disposal of Radioactive Waste by the User (1985), which sets out guidelines and safe practices for the disposal of very low-level waste. State/Territory regulations usually contain additional requirements to the Code, with which users are required to comply.

All radioactive materials in Western Australia are regulated by the *Radiation Safety Act 1975.* Only waste generated in Western Australia may be disposed of at the IWDF. Radiation Protection Standards are based on ICRP and IAEA guidelines, and controlled by the Radiological Council (a statutory body set up under the *Radiation Safety Act).* Western Australia's IWDF is regulated by the

Department of Environmental Protection under the *Environmental Protection Act 1986* and is subject to stringent conditions of operation and management.

Operator

Proposed National repository: the operator will be decided once a preferred site is selected.

Western Australia's IWDF: the Waste Management Division of the WA Department of Environmental Protection.

Time schedule

Name	Construction	Opening	First disposal	Closure	Period of institutional control
Proposed National repository	To be decided		50 years of operation is envisaged		100-300 years
WA's IWDF	1992	1992	1992	N.A.*	to 2095

* N.A. = Not available

Capacity

Name	Total capacity (m^3)	Annual delivery
Proposed National repository	N.A.	N.A.
WA's IWDF	No limit has yet been specified	(6 000 t of gangue/ year is proposed)

Facility

Proposed National repository

Although it has been decided that the national radioactive waste repository will be a near-surface facility, details of the design have not been finalised.

Western Australia's IWDF

The Western Australian IWDF includes a near-surface disposal facility for LLW. As well as waste from the medical, industrial and research uses of radionuclides, the facility is expected to eventually accept radioactive waste from rare earths' processing.

2.3.2 Belgium

Policy and strategy regarding radioactive waste disposal

ONDRAF/NIRAS, the Belgian Agency for Radioactive Waste Management is entrusted with all aspects related to waste management in Belgium, including final disposal. The present reference scenario foresees a shallow land disposal route for LLW and VLLW after a period of interim storage. No site has yet been selected. Interim storage is operated at Mol-Dessel before disposal scheduled for around 2004. The waste is mainly produced from the electricity sector. Other sources are fuel manufacturing, research, radioisotope uses and historical facilities.

Regulation regarding waste categories and disposal

The site can accommodate both LLW and VLLW. No difference is made between these two waste forms. The acceptability of waste for shallow-land disposal depends on the quantities of long-lived radionuclides present. With regard to radiation protection and safety standards, not all regulatory aspects have been settled as yet by the regulatory authorities.

Operator

The repository will be operated by ONDRAF/NIRAS, owned by the Belgian State.

Time schedule

Beginning of construction	Completion of construction	Opening	First disposal	Closure	Period of institutional control
1999-2001	2004	2004	2004	2070	200-300 years

Capacity

Total capacity (m^3)	Annual delivery (m^3)
60 000-100 000	~ 1 000

Facility

The repository is a shallow-land type. Retrievability is not required. The design described by ONDRAF/NIRAS in their feasibility report is based on the concept of multiple protective barriers. The engineered barriers are designed to minimise both rainwater inflow and the leakage of any radionuclide contaminated water from the inside. In addition, the geology must be able to trap escaping nuclides, or to channel them into well defined zones. Until the repository is in operation (around 2004), LLW will continue to be stored in the interim storage facilities at Mol-Dessel.

2.3.3 Canada

Policy and strategy regarding radioactive waste

Natural Resources Canada (NRCan) is the department of the Federal Government responsible for energy policy, including nuclear energy and extending to radioactive waste management. In 1996, NRCan announced a policy framework for Radioactive Waste that will guide Canada's approach to the disposal of nuclear fuel waste, low-level radioactive waste and uranium mine and mill tailings into the next century. The framework lays out the ground rules and sets the stage for the further development of institutional and financial arrangements to implement disposal in a safe, environmentally sound, comprehensive, cost-effective and integrated manner. The waste producers and owners are responsible for the funding, organisation, management and operation of disposal facilities and other facilities required for their waste.

Regulation regarding waste categories and disposal

Radioactive waste management is regulated by the Atomic Energy Control Board (AECB), through the Atomic Energy Control Act and regulations pursuant to the Act. The objectives of radioactive waste disposal, as stated in the AECB regulatory guideline (R-104) are to minimise any burden placed on future generations and to protect the environment and human health, taking into account social and economic factors.

A general requirement for disposal, in R-104, is that the predicted radiological risk to individuals from a waste disposal facility shall not exceed 10^{-6} fatal cancers and serious genetic effects in a year, calculated without taking advantage of long-term institutional controls as a safety feature.

There is no formal categorisation of low-level waste for disposal or management. For administrative purposes, low-level waste is divided into two broad classes or categories: waste produced on an ongoing basis; and waste which has resulted from historical activities.

Facility

Several initiatives for disposal are currently underway and at various stages of progress, as detailed in the country annex for Canada. A repository is yet to be established and all waste is currently in storage at licensed facilities.

Operator, time schedule and *capacity* have not been established yet.

2.3.4 Czech Republic

Policy and strategy regarding radioactive waste disposal

In the Czech Republic, there are in practice two separate and mutually independent systems for the handling of radioactive waste. The responsibility for handling waste generated outside the nuclear fuel cycle (institutional waste) rests with the joint stock company ARAO (Agency for Radioactive Waste) which operates two repositories, Richard and Bratrství. The responsibility for waste produced by the nuclear power engineering facilities is borne by the operator of the nuclear power plants, i.e. CEZ, a.s. which operates the Dukovany repository. A new Nuclear Law is proposed, under which the responsibility for disposal of all radioactive waste will pass to the State and the waste disposal activity will be carried out by a national agency. The sources of waste are nuclear power plants, research, other radionuclide users and historical waste from decommissioning of radionuclide laboratories.

Regulation regarding waste categories and disposal

For the Richard repository, the total and specific activity limits for critical radionuclides are given. For the Bratrství repository, the limits have not yet been specified. The limits and conditions applied to the Dukovany repository allow the disposal of service effluents which can be classified as LLW and ILW waste. Where waste cannot meet the specified limits for the Dukovany repository then disposal in other repositories is possible provided that the respective conditions for acceptance are met. Exemption levels will be specified in the new Decree on requirements for radiation protection (No. 184/1997). All radiation protection and safety standards are now reviewed by the State Office for Nuclear Safety in connection with the new nuclear law which will be valid as of 1 July 1997.

Operator

Dukovany: CEZ, a.s., the operator of the nuclear power plants. The State is a major shareholder.
Richard: ARAO, the private Agency for Radioactive Wastes with some State participation.
Bratrství: ARAO, the private Agency for Radioactive Wastes with some State participation.

Time schedule

Name	Construction	Opening	First disposal	Closure	Period of institutional control (years)
Dukovany	1987-1994	1994	1994	2040	300
Richard	1962-1964	1964	1964	2035	300
Bratrství	1972-1973	1974	1974	2035	300

Capacity

Name	Total capacity (m^3)	Delivery
Dukovany	30 000-35 000	430 (m^3/year)
Richard	9 450 for LLW 1 050 for ILW	7 m^3/day for LLW 4 m^3/day for ILW
Bratrství	260 for LLW 30 for ILW	5 m^3/day for LLW 2 m^3/day for ILW

Facility

Dukovany

The repository is an above ground vault. Retrievability is not required. Radioactive waste is placed in 200-litre drums which are stacked in layers up to six high. Consideration is being given to filling the free spaces with concrete.

Richard and Bratrství

Both repositories are underground disused mines. Retrievability is not required. Radioactive waste (in 200-litre drums) is stacked in 4 to 7 layers. Multi-layered lead, depleted uranium, concrete or barytes-concrete shielding is employed depending on the activity contained in the waste.

2.3.5 Finland

Policy and strategy regarding radioactive waste disposal

The two nuclear utilities, Teollisuuden Voima Oy (TVO) and Imatran Voima Oy (IVO) are responsible for the safe management of waste, for the necessary R&D work and for meeting the costs of waste management. TVO and IVO store and dispose of the operating waste at the power plant sites, TVO in Olkiluoto and IVO in Loviisa. The Ministry of Trade and Industry determines the fees that the utilities pay into a Nuclear Waste Fund to cover the future costs of waste management.

Regulations regarding waste categories and disposal

Nuclear waste management is regulated by the Nuclear Energy Act, which came into force in 1988. Radiation protection and third party liability are regulated by specific acts. There are safety regulations for waste handling, storage and disposal of low and intermediate-level operating waste. In 1983, the Council of State made a policy decision on nuclear waste management. The decision stipulates the principles, objectives and time schedules for research, planning and implementation of waste management. The main regulating authorities are the Ministry of Trade and Industry and the Finnish Centre for Radiation and Nuclear Safety (STUK). STUK regulates implementation of waste management and issues safety guides. Licences for the construction and use of nuclear facilities are granted by the Council of State (Government).

Nuclear waste is divided into three categories: operating waste (low and medium level); spent nuclear fuel (high level); and decommissioning waste (low and medium level).

Operator

Olkiluoto: TVO, owned 57 per cent by PVO (a private utility), 27 per cent by IVO and 16 per cent by the public.
Loviisa: IVO, a state-owned utility.

Time schedule

Name	Beginning of construction	Completion of construction	First disposal	Closure	Period of institutional control
Olkiluoto	1987	1991	1992	~ 2060	Not decided
Loviisa	1993	1996	1998	~ 2050	Not decided

Capacity

Name	Total capacity (m^3)	Annual delivery (m^3)
Olkiluoto	4 960 for LLW 3 472 for ILW	224
Loviisa	2 400 for LLW 3 000 for ILW	N.A.

Facility

Both repository designs are cavern type, in crystalline bedrock, and allow for extension of the facilities to take decommissioning waste from the respective power stations.

2.3.6 France

Policy and strategy regarding radioactive waste disposal

In France, the radioactive waste management system implemented in the 1960s was significantly modified in 1991, when a Waste Act was introduced by the French Parliament. The new law clearly defines the responsibilities of all parties involved in radioactive waste management. In particular, the status of the French national radioactivity management agency, ANDRA, was changed, to give the agency greater autonomy and responsibility. Radioactive waste is managed in compliance with Fundamental Safety Rules, set by the regulatory authorities. Low and intermediate-level short-lived radioactive waste is disposed of in near-surface facilities. Regarding long-lived and high activity level wastes, a R&D programme, initiated by the 1991 Waste Act, will contribute to a decision around 2006 on the preferred solution. Disposal of waste in deep geological formations is one of the investigated options.

Regulations regarding waste categories and disposal

The Directorate for the Safety of Nuclear Installations (DSIN) is responsible for defining and implementing nuclear safety policies and regulations. The DSIN reports to the Ministries of Industry and the Environment. The technical requirements for waste acceptance and disposal are derived from Fundamental Safety Rules. The type and activity of radionuclides acceptable for surface disposal are primarily beta/gamma emitters with half-lives of 30 years or less. Very low amounts of alpha emitters are accepted in near-surface repositories.

Very low-level radioactive waste is not disposed of at the ANDRA Centre de l'Aube surface repository, designed and operated for low and intermediate-level waste. A new near-surface facility will be constructed in the near future and dedicated to VLLW.

Operator

All radioactive waste near-surface disposal facilities in France are operated by ANDRA.

Time schedule

Name	Beginning of construction	Completion of construction	First disposal	Closure	Expected period of institutional control
L'Aube	1987	1991	1992	2050	300 years
La Manche	–	–	1969	1994	300 years

Capacity

Name	Total capacity (m^3)	Annual delivery (m^3)
L'Aube	1 000 000	17 600
La Manche	530 000	N.A.

Type

Both repositories are near-surface facilities. Retrievability is not required. Radioactive waste is contained either in metallic drums or in concrete boxes. At the Centre de l'Aube, waste packages are disposed of in concrete structures. A multi-layer cap will protect the disposal zone from rainwater after operation.

2.3.7 Germany

Policy and strategy regarding radioactive waste disposal

The responsibility for final disposal of radioactive waste, included in the portfolio of the Ministry for the Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, BMU), was transferred by the Government to the Federal Office for Radiation Protection (Bundesamt für Strahlenschutz, BfS). Since the early sixties, the radioactive waste disposal policy in the Federal Republic of Germany has been based on the decision that all kinds of radioactive waste are to be disposed of in deep geological formations, e.g. rock salt. Near-surface disposal is not practised in the Federal Republic because of a high population density, climatic conditions and existing appropriate deep geological formations. The present scenario for LLW disposal is to use the operating Morsleben repository in Saxony-Anhalt, an abandoned salt mine, and the planned Konrad repository in Lower Saxony, an abandoned iron ore mine, for which a licence has been requested. The Gorleben salt dome in Lower Saxony is under investigation for HLW and all other types of radioactive wastes.

The waste is mainly produced by the electricity sector. Other sources are research facilities, radioisotope use in medicine and industry and spent sealed radiation sources from other users.

Regulations regarding waste categories and disposal

The Morsleben repository accepts LLW and certain categories of ILW. The categorisation of radioactive waste considers both the physical and radiological characteristics of the waste. The radiological characteristics are used to classify the waste into radiation protection groups. Radioactive waste in radiation protection groups S1 and S2 can be considered as LLW and those of radiation protection groups S3, S4 and S5 as ILW (see Annex 2). Heat generating ILW, e.g. originating from spent fuel reprocessing, is not accepted at Morsleben.

The planned Konrad repository is assigned to accept all types of radioactive wastes with negligible heat generation, i.e. waste packages which do not increase the host rock temperature by more than 3°K on average. Therefore, according to the German radioactive waste disposal concept, waste from decommissioning can also be placed in the planned Konrad repository.

Operator

Morsleben is operated by BfS and they will also operate Konrad. BfS is a government body.

Time schedule

Name	Beginning of construction	Completion of construction	Opening	First disposal	Closure	Period of institutional control
Morsleben	1973	1978	1978	1978	after 2000	Not necessary
Konrad	1998	2000	2001	2001	2040	Not necessary

Capacity

Name	Total capacity (m^3)	Annual delivery (m^3)
Morsleben	54 000	5 000 (10 000 from 1998)
Konrad	650 000	16 250

Facility

Both repositories are deep geological formation types in sedimentary rock; Morsleben is in rock salt and Konrad in a sedimentary iron ore formation. Retrievability is not required. In both cases the main barriers are the overlaying strata, several hundred metres thick. There is no rainwater inflow. Long-term safety analyses show that in the post-closure phase radionuclides which might reach the biosphere via deep groundwater transport processes do not lead to individual dose rates exceeding the limit value specified in section 45 of the Radiation Protection Ordinance (0.3 mSv/y).

2.3.8 Hungary

Policy and strategy regarding radioactive waste disposal

The application of atomic energy has been regulated in Hungary by Act No. 1, 1980, but is now superseded by a new law on atomic energy passed by the Hungarian Parliament in December 1996, and applied from 1 June 1997. Decrees and rules for its implementation are being revised. An independent organisation was established in 1997 for the management of the final disposal of radioactive waste and for the decommissioning of nuclear facilities. Since 1976 a near-surface repository has been in operation at Püspökszilágy which receives LLW and ILW generated from research institutes, isotope production, hospitals, etc. Over the last 12 years, LLW from the Paks nuclear power plant (NPP) has also been disposed in this repository. Exploration for a new site for disposal of LLW from nuclear power plants is in progress.

Regulations regarding waste categories and disposal

Hungarian waste classification is based on activity concentration in the waste as follows:

Low level	less than 5 x 10^5 kBq/kg
Medium level	5 x 10^5 to 5 x 10^8 kBq/kg
High level	greater than 5 x 10^8 kBq/kg

Operator

The existing repository is operated by the State Public Health and Medical Officers' Services. A new independent organisation will take over operation of the existing and future repositories.

Time schedule

Name	Beginning of construction	Completion of construction	Opening	First disposal	Closure	Period of institutional control
New	1998/99	2001/2002	2002	N.A.	N.A.	100 years if Udvari is selected
Püspökszilágy	1974	1976	1976	1977	N.A.	100 years

Capacity

Name	Total capacity (m^3)	Annual delivery (m^3)
New	40 000	1 140
Püspökszilágy	5 000	237

Facility

The existing facility (Püspökszilágy) is a near-surface disposal site. Retrievability is not required.

The planned (New) facility will be either near surface (Udvari) or a 100-150 metre deep geological repository (Üveghuta). Retrievability will be required.

2.3.9 Italy

Policy and strategy regarding radioactive waste disposal

The producers of radioactive waste are:

- ENEL S.p.a., the national electricity utility;
- ENEA, the national research and development body for alternative energies;
- hospitals, industry, research institutes and universities.

Intermediate and low-level waste presently stored in Italy amounts to around 21 000 m^3 and of this approximately 5 500 m^3 is associated with nuclear power generation, and is stored at the plants. Other intermediate and low-level waste, associated with research, medical and industrial activities, is stored at producer storage facilities or is collected in authorised centres.

The intermediate/low-level waste arising from ENEL nuclear power plants is treated to produce a wasteform suitable for disposal, according to the requirements of Technical Guide No. 26. The waste management arrangements differ from one plant to another depending on reactor type and on specific plant restrictions. Intermediate and low-level waste produced during nuclear power plant operation mainly belongs to the second category of waste (as defined in Technical Guide No. 26). Annex 2 gives further data about intermediate and low-level waste produced and stored at ENEL nuclear power plant sites.

Regulations regarding waste categories and disposal

All aspects relating to the peaceful use of nuclear energy are basically regulated by law. The ANPA (National Agency for Environment Protection) is responsible for all safety and regulatory aspects of radioactive waste management, including final disposal. ANPA has been entrusted with the duties of the former ENEA-DISP (Italian Directorate for Nuclear Safety and Radiation Protection).

Radioactive waste management in Italy is not specifically regulated by law; however, the safety authority has issued a guide (Technical Guide No. 26) that deals specifically with radioactive waste management, and this guide is now being applied. This guide is particularly conservative because it has to ensure the disposal of radioactive waste, whichever type of final repository is chosen. The Country Annex provides an outline of Technical Guide No. 26.

Time schedule

A final repository for radioactive waste is not available in Italy. Moreover the type of repository has yet to be defined by the competent authorities. The evaluation of possible sites for the final repository has been carried out and potentially suitable sites for the disposal of radioactive waste have already been found, although no research to confirm their suitability has started due to strong local opposition. Recently, on the initiative of the Italian Government, activities have been restarted for the selection of a site for the national final waste disposal repository.

2.3.10 Japan

Policy and strategy regarding radioactive waste disposal

In Japan, the basic framework for nuclear research, development and utilisation, including regulation of those activities, is set out in the Atomic Energy Fundamental Law. According to this framework, the Atomic Energy Commission (AEC) is in charge of deciding the national policy and strategy for those activities that involve radioactive waste disposal.

Radioactive waste disposal is regulated either by the Regulative Act for Nuclear Source Materials and Nuclear Reactors (Reactor Regulation Law) or the Act for the Prevention of Radiation Hazards due to Radioisotopes and other sources. (Radiation Hazard Prevention Law), depending on the facility generating the waste. A number of laws, orders and standards have been established to ensure safe radioactive waste disposal. The Radiation Council was set up to harmonise the technical standards for the prevention of radiation hazards. The Nuclear Safety Commission (NSC) has the special task of formulating and maintaining guides.

The cumulative amount of radioactive waste generated from nuclear reactors to the end of March 1995 was about 563 400 drums, of which 49 600 drums have already been shipped to the disposal facility.

Regulations regarding waste categories and disposal

The Reactor Regulation Law requires that all LLW from nuclear reactors is disposed of on land. The Law allows two principal methods. LLW may be disposed of by solidifying the waste in a container and disposing of the containers in shallow burial facilities provided with engineered barriers. For very low-level radioactive concrete waste from reactor decommissioning, there is the alternative of disposal in shallow burial facilities without engineered barriers. There is no definite threshold between LLW and VLLW, they are regulated by upper limits on the radioactivity concentration permitted for land disposal for each of the methods mentioned above. An exemption level for radioactive waste has not yet been established.

Operator

The repository is operated by Japan Nuclear Fuel Limited (JNFL). JNFL is a private company and its stock is 71 per cent owned by Japanese utilities.

Time schedule

Name	Beginning of construction	Completion of construction	Opening	First disposal	Closure	Period of institutional control
Rokkasho No. 1	1990	1992	1992	1992	2012	300 years
Rokkasho No. 2	1998	2000	2000	2000	2012	300 years

Capacity

Name	Total capacity (m^3)	Annual delivery (m^3)
Rokkasho No. 1	40 000	~ 5 000
Rokkasho No. 2	40 000	~ 5 000

Facility

The repository is a shallow ground vault type situated below the groundwater table. Retrievability is not required. The burial facility is divided into eight sectors, each of which consists of 5 vaults and capable of holding about 5 000 m^3 of waste. Each vault of reinforced concrete is internally divided into 16 cells, each of which can accept 320 drums. After LLW is placed into the reinforced concrete cell, the spaces between the drums are sealed by a cement-base mortar grout. The vaults will be closed with a reinforced concrete lid and the burial facility backfilled with a bentonite-soil mixture topped by soil more than 4 metres thick. Furthermore, a porous concrete layer will be provided on the inside of the outer walls of the vaults to prevent the entry of groundwater. If underground water penetrates into the vault through the outer wall, it will pass through this porous concrete layer to be discharged into an inspection tunnel outside the burial facilities.

2.3.11 Korea

Policy and strategy regarding radioactive waste disposal

In 1996, the government amended its policy on the national radioactive waste management programme making KEPCO (Korea Electric Power Corporation), the national electric utility and main producer of radioactive waste, responsible for the practical aspects of radioactive waste management such as siting, design and construction as well as operation of a radioactive waste and spent fuel management facility, including the management of wastes from medical use, industry and research.

No site has yet been selected. The radioactive waste management programme, including site selection for the repository will be established in 1998. The data provided in Annex 2 are based on the conceptual design of a rock cavern-type LLW repository.

Regulation regarding waste categories and disposal

The planned repository can accommodate low-level waste (LLW). In Korea radioactive waste is managed in compliance with the Atomic Energy Law. Radioactive waste is classified into two categories, depending on the surface dose rate of the solid waste:

Low-Level Waste (LLW)	Solid waste with surface dose rate lower than 2 000 mR/h.[1]
High-Level Waste (HLW)	Solid waste with surface dose rate of 2 000 mR/h or more.

1. 1 Röntgen = 2.58×10^{-4} Coulomb/kg.

Disposal of LLW is managed in accordance with several governmental notices on design basis, siting criteria, acceptance conditions and performance objectives of the repository.

The performance objectives of radioactive waste disposal are to :

- minimise any burden placed on future generations;
- protect the environment and human health; and
- ensure that the predicted radiological risk to individuals of fatal cancer or serious genetic effects shall not exceed 10^{-6}/year.

Operator

The repository will be constructed and operated by KEPCO. KAERI, the Korea Atomic Energy Research Institute, had previously been responsible for operation of the proposed repository before the transfer of responsibility for radioactive waste management to KEPCO in December 1996.

Time schedule

As the new radioactive waste management programme is to be formulated in 1998, a fixed time schedule is not available at present. KEPCO can store LLW until 2010 at the nuclear power plant sites.

Capacity

Total capacity (m^3)	Annual delivery (m^3)
20 000	2 000

Facility

The conceptual design of the planned repository is for a rock cavern type. Retrieval is not required. The concept includes natural and engineered barriers.

2.3.12 Spain

Policy and strategy regarding radioactive waste disposal

The strategy applied to LLW in Spain is based on the establishment of two major courses of action. The first deals with the conditioning, transport and characterisation of LLW and the second with the design, construction, operation and closure of the disposal facilities.

The treatment and conditioning of LLW is the responsibility of the producer, except in the case of small producers (research, medicine, industry, etc.). The packages generated must satisfy the acceptance criteria as defined by the National Enterprise for Radioactive Waste (ENRESA) and approved by the authorities, for subsequent conditioning and disposal at the El Cabril facility. In the case of small producers, waste treatment and conditioning is carried out at the El Cabril installation. The relationship between ENRESA and waste producers is managed through specific contracts.

Regulations regarding waste categories and disposal

The Ministry of Industry and Energy (MIE) is responsible for enforcing nuclear legislation and for granting licenses (Law 25/1964, Decree 2869/1972), subject to the mandatory and binding report of the Nuclear Safety Council (CSN). The CSN was set up in 1980 (Law 25/1980) as the only competent body in matters of nuclear safety and radiological protection and is generally responsible for the regulation and supervision of nuclear installations; this body is independent from the State Administration and reports directly to Parliament. The Ministry of Environment participates in the Environment Impact Assessment with the CSN. Regional and local authorities also participate in the licensing process within their areas of competence.

The waste to be disposed of at the El Cabril facility contains low specific activity beta-gamma emitting radionuclides (with a half-life of less than 30 years) and with a limited content of long-lived alpha emitters less than (3.7×10^3 Bq/g).

Operator

The repository is operated by ENRESA.

Time schedule

Beginning of construction	Completion of construction	Opening	First disposal	Closure	Period of institutional control (years)
1990	1992	1992	1993	N.A.	300

Capacity

Total capacity (m^3)	Annual delivery (m^3)
100 000	5 000

The volumes indicated for capacity and annual delivery refer to ready for disposal waste packages. Due to overpacking, the volume of the waste as delivered is increased by a factor of 2.4.

Facility

The El Cabril facility has two main areas, one for waste disposal and the other for conditioning, auxiliary buildings, and the waste quality verification laboratory.

The repository is a shallow-land type with engineered barriers. Retrievability is required. The disposal system is made up of a set of multiple barriers, within which the waste packages are immobilised by means of mortar inside concrete containers. These containers are placed in contact with each other in the disposal vaults.

2.3.13 Sweden

Policy and strategy regarding radioactive waste disposal

SKB (Swedish Nuclear Fuel and Waste Management Co.) is owned by the Swedish Nuclear Power utilities and has been appointed as responsible for the management of Sweden's radioactive waste.

The final repository for radioactive operational waste, SFR, has been in operation since 1988. All the low and intermediate-level short-lived waste from the operation and maintenance of the nuclear power plants is disposed of in SFR, along with radioactive waste from medical use, industry and research.

Regulations regarding waste categories and disposal

SFR has five different rock chambers for disposal of different kinds of waste. The most active waste is disposed of in a concrete silo surrounded by a clay buffer. The other four chambers consist of a cavern for low-level waste (BLA), two caverns for concrete tanks with dewatered ion exchange resins (BTF1 and BTF2) and a cavern for intermediate-level waste (BMA). BMA and the silo are for intermediate-level waste and the three other caverns are for low-level waste.

The license for SFR allows 10^{16} Bq, mainly short-lived nuclides to be disposed. Which rock vault the waste package will be allocated to depends on the origin of the waste, the geometry, treatment process and the surface dose rate on the package.

LLW is defined as waste that can be handled without any special radiation shielding.

Prior to waste disposal in SFR, SKB has to get approval from the authorities, the Swedish nuclear power inspectorate (SKI) and the Swedish radiation protection institute (SSI).

A satisfactory safety evaluation will be required before permission will be given to seal the repository.

Operator

The repository is owned by SKB, and operated by the staff of the Forsmark Power Plant which is situated close to the repository.

Time schedule

Beginning of construction	Completion of construction	Opening	First disposal	Closure	Period of institutional control
1983	1988	1988	1988	Not yet decided	Not necessary

Capacity

Total capacity (m^3)	Daily delivery (m^3)
15 600 for LLW, 48 300 for ILW including packaging	30

Facility

SFR consists of an above ground section and an underground section. The above ground section consists of office, workshop, terminal building for transport containers and building ventilation. The repository is situated in crystalline bedrock, more than 50 metres below the seabed. Retrievability is not required.

2.3.14 Switzerland

Policy and strategy regarding radioactive waste disposal

Nuclear power production is the main source of Swiss radioactive waste, although waste arises also in medicine, industry and research. Two separate geological repositories are planned: one for LILW (LLW repository) and another for HLW and ILW containing higher concentrations of long-lived nuclides (HLW/ILW repository). With respect to the fuel cycle, Swiss disposal planning has to date been focused on waste returned from foreign reprocessing plants, and currently the preferred strategy of the utilities is to keep both options open (reprocessing or direct disposal).

Regulations regarding waste categories and disposal

The Atomic Law of 1959 clearly placed the responsibility for nuclear waste disposal with the producer of the waste. The ruling of 1978 then stipulated that “The general licence for nuclear reactors will be granted only when the permanent, safe management and final disposal of radioactive waste is guaranteed”. The safety conditions which the final repositories must satisfy are defined in

Guideline R-21 (1980, revised 1993) of the Nuclear Regulatory Authorities. Three Protection Objectives have been defined:

a) "The release of radionuclides from a sealed repository, subsequent to processes and events reasonably expected to happen, shall at no time give rise to individual doses which exceed 0.1 mSv per year."

b) "The individual radiological risk of fatality from a sealed repository, subsequent to unlikely processes and events not taken into consideration in Protection Objective a), shall at no time exceed one in a million per year."

c) "After a repository has been sealed, no further measures shall be necessary to ensure safety. The repository must be designed in such a way that it can be sealed within a few years."

Licensing is a complicated, lengthy procedure. On the Federal level, licensing of a radioactive waste repository is a multistage process. In addition to the Federal licences, cantonal and community licences also have to be obtained. The public has various opportunities to lodge objections or to participate in discussions.

Operator

Nagra is responsible for all technical and scientific work associated with preparing for waste disposal. The low-level waste repository at Wellenberg will be constructed and operated by the "Genossenschaft für Nukleare Entsorgung Wellenberg" (GNW) which will be domiciled in the siting community. The members of this co-operative are the operators of nuclear power plants and the siting community. The siting canton and the Federal Government, responsible for medicine, industry and research can also become members of GNW.

Time schedule

The data presented in this report is based on a LLW repository concept with two operating phases (2007-2018 and 2025-2040).

Capacity

For this concept, a conservatively assessed total LLW volume of 200 000 m^3 has been assumed, including 57 000 m^3 of decommissioning waste. The LLW large total volume is due to the volume increase by an average factor of 3.3 resulting from the overpacking at the repository site of all wastes other than decommissioning waste. Details are given in Annex 2.

Facility

Two separate geological repositories are planned: one for short-lived LLW/ILW (LLW repository) and another for HLW and ILW containing higher concentrations of long-lived nuclides (HLW/ILW repository). There is no formal definition of LLW, i.e. no threshold value has been established for LLW. The concept of VLLW is not used in Switzerland. For planning purposes, the key waste streams are allocated to LLW/ILW and HLW/ILW respectively as follows:

- LLW repository: operational waste from nuclear power plants, waste from medicine, industry and research, decommissioning waste from nuclear power plants and research facilities as well as LLW from fuel cycle, especially from reprocessing; and

- HLW/ILW repository: ILW from fuel cycle, especially from reprocessing, vitrified HLW from reprocessing and conditioned spent fuel elements (direct disposal).

2.3.15 United Kingdom

Policy and strategy regarding radioactive waste disposal

Government policy is that low-level radioactive waste disposal is in existing near-surface disposal facilities located at Drigg (Cumbria) and Dounreay (Caithness). Dounreay only receives waste from the nuclear facilities at Dounreay and consequently the Drigg site essentially operates as the national disposal facility. The major waste producers are the nuclear fuel cycle industry, defence industry and the electricity sector. Other sources are radio-pharmaceutical manufacturers, hospitals and research institutes.

Regulations regarding waste categories and disposal

The Drigg site accepts only low-level radioactive waste defined as "wastes having a specific activity of not more than 4 GBq/t alpha or 12 GBq/t beta-gamma".

Radiological protection principles in the United Kingdom are based on ICRP 60 and therefore the dose rate for members of the public from the operation of a nuclear facility is limited to 1 mSv/year. In addition, a dose constraint for the operation of a new facility has been set at 0.3 mSv/year with the requirement that where existing sources could not meet this figure, then the operator must demonstrate that the doses resulting from the continued operation of a facility are as low as reasonably achievable and within the dose limit. With regard to the long term risks from a disposal site, the view is that the nature of a disposal system makes it less amenable to quantified risk assessments than is the case, for example, for nuclear reactors. Reliance is not therefore placed exclusively on estimates of risk to determine whether a disposal facility is safe. While such calculations can inform a judgement about safety of a facility, other technical factors, including ones of a more qualitative nature, are also considered in arriving at a decision. Nevertheless, a risk target is used as an objective in the design process and this is set at 10^{-6} per year for fatal cancer or a serious hereditary effect.

Operator

The Drigg disposal site is owned and operated by British Nuclear Fuels plc.

Time schedule

Period of construction	Opening	First disposal	Closure	End of institutional control
–	1959	1959	2050	2170

Capacity

Total capacity (m^3)	Annual delivery (m^3)
850 000 for trenches	Trenches are filled
800 000 for vaults	12 000

Facility

The repository is a shallow land type. Initially waste was disposed into trenches cut into a clay layer which underlies much of the site. Disposal is now carried out in engineered concrete vaults with the emplacement of grouted containers of treated (high force compacted) waste.

2.4 Summary of LLW disposal in NEA countries

Information on the general situation of LLW disposal in NEA Member countries mentioned above is summarised in Table 2-1.

Table 2-1. **Summary of LLW disposal in NEA countries**

Country	Disposal facility	Acceptable waste	Waste origin	Disposal method	Capacity (m^3)	First disposal	Disposed waste until 07/95 (m^3)	Post-closure monitoring (years)	Safety/Regulatory organisation	Ownership/ Operator
Australia	Proposed national repository	LLW, ILW (short-lived)	Research, medical and industrial uses	Near surface	Not decided	Not decided	0	100-300	To be decided	To be decided
	IWDF	LLW (lower activities than the specified limits and categories A, B and C of NHMRC Code)	Medical, educational and research applications; by-products of processing of mineral sands, etc.	Near surface; Shaft and trench less than 40 m deep	No limit has yet been specified	1992	125	100	Radiological Council of Western Australia	Department of Environmental Protection of Western Australia
Belgium	Not decided	LLW, VLLW: lower activities than the specified limits	NPP, fuel manufacturing, research; radioisotope uses	Near surface; Vault	60 000 to 100 000 (planned)	2004	0	200-300	Ministry of Employment Ministry of Public Health	ONDRAF/NIRAS, Belgian agency
Canada	IRUS (prototype)	LLW: radwaste except HLW, U mine and mill tailings	NPP; research	Near surface; Vault	2 000	1999	0	Not decided	AECB	AECL, a national organisation
Czech Republic	Dukovany	LLW, ILW: lower total inventories than the specified limits	NPP	Near surface; Vault: 5 m above ground	30 000 to 35 000	1994	270	300*	State Office for Nuclear Safety	CEZ, electricity utility owned mainly by the State.
	Richard	LLW, ILW: lower surface dose rate than 1 mSv/h	Waste from outside the nuclear fuel cycle	Subsurface; Disused mine; Vault: 52 m deep	10 500 (designed)	1964	2 000	200-300		ARAO, a private company with some State participation. Following the 1997 Atomic Act, these repositories will become the property of the state and will be run by the Radioactive Waste Repository Authority no later than February 2000.
	Bratrství	LLW, ILW: lower surface dose rate than 1 mSv/h	Wastes containing only natural radio-nuclides	Subsurface; Vault: 50 m deep	290	1974	250	200-300		

* Expected.

NPP = Nuclear Power Plant

Table 2-1. **Summary of LLW disposal in NEA countries** (continued)

Country	Disposal facility	Acceptable waste	Waste origin	Disposal method	Capacity (m^3)	First disposal	Disposed waste until 07/1995 (m^3)	Post-closure monitoring (years)	Safety/Regulatory organisation	Ownership/ Operator
Finland	Olkiluoto	LLW, ILW	NPP	Subsurface; Silo: 70 to 110 m deep	8 432	1992	2 070	Not decided	KTM (The Ministry of Trade and Industry)	TVO, a private utility
	Loviisa	LLW, ILW	NPP	Subsurface; Cavern: 120 m deep	5 400	1998	0	Not decided	STUK (Finnish Centre for Radiation and Nuclear Safety)	IVO, a state-owned utility
France	Centre de la Manche	LLW, ILW: lower activities than the specified limits	NPP; fuel cycle, research; radioisotopes	Near surface; Tumuli and vaults	530 000	1969 (closed in 1994)	530 000	300*	DSIN (Directorate for the Safety of Nuclear Facilities)	ANDRA, French National Radwaste Management Agency
	Centre de l'Aube			Near surface; Vault	1 000 000	1992	32 900	300*		
Germany	ERAM (Morsleben)	VLLW, LLW, ILW: all types of radwaste with negligible heat generation and limited surface dose rate	NPP; research; radioisotopes; spent sealed radiation sources	Subsurface; Disused salt mine; Cavern: 500 m deep	54 000	1978	17 750 (and 6 542 pieces spent sealed radiation sources)	Not necessary	BMU (The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety)	BfS, Federal Office for Radiation Protection. DBE, the German company for the construction and operation of waste repositories carries out the construction and operation under contract for BfS
	Konrad	VLLW, LLW, ILW: all types of radwaste with negligible heat generation and limited surface dose rate	NPP; research; radio-isotopes	Subsurface; Disused iron mine; Cavern: 1 000 to 1 300 m deep	650 000	2001	0	Not necessary		

Table 2-1. **Summary of LLW disposal in NEA countries** (continued)

Country	**Disposal facility**	**Acceptable waste**	**Waste origin**	**Disposal method**	**Capacity (m^3)**	**First disposal**	**Disposed waste until 07/95 (m^3)**	**Post-closure monitoring (years)**	**Safety/Regulatory organisation**	**Ownership/ Operator**
Hungary	Radwaste Treatment and Disposal Facility (Püspökszilágy)	LLW, ILW: lower than the specified activities limits or surface dose rates	Medical uses; NPP (temporarily)	Near surface; Vault: 6 m deep	5 000	1977	4 500	Not decided	The Ministry of Public Welfare	Municipal Institute of State Public Health and Medical Officer Services, a state-owned company
	Udvari (New)	LLW, ILW	NPP	Near surface; Vault: 5 m deep	40 000	Planned	0	Not decided		The Radioactive Waste Management Agency, an independent organisation, is to be established in 1998.
	Üveghuta (New)	LLW, ILW	NPP	Subsurface; Cavern: 100 to 150 m deep	40 000	Planned	0	Not decided		
Italy	Under siting	To be defined	NPP (operation, maintenance and decommissioning); Medicine, industry and research	To be defined	To be defined	To be defined	0	Not decided	ANPA (National Agency for Environment Protection)	To be defined
Japan	Rokkasho LLW Disposal Centre, No. 1 Disposal Facility	LLW: lower activities than the specified limits	NPP	Near surface; Vault: 14 to 19 m deep	40 000	1992	9 408	~ 300	Science and Technology Agency	Japan Nuclear Fuel Ltd., a private company, mainly owned by utilities
	No. 2 Disposal Facility			Near surface; Vault: 16 to 21 m deep	40 000	Under licensing	0	~ 300		
Korea	Under siting	LLW: lower surface dose rate than 20 mSv/h	NPP	Subsurface; Cavern	20 000 Conceptual designing	To be defined	0	Not decided	MOST (Ministry of Science and Technology)	KEPCO, a public utility

Table 2-1. **Summary of LLW disposal in NEA countries** (continued)

Country	Disposal facility	Acceptable waste	Waste origin	Disposal method	Capacity (m^3)	First disposal	Disposed waste until 07/95 (m^3)	Post-closure monitoring (years)	Safety/Regulatory organisation	Ownership/ Operator
Spain	El Cabril	LLW, ILW: lower activities than the specified limits	NPP; fuel fabrication plant; medicine; industry and research	Near surface; Vault	100 000	1993	9 913	~ 300	MIE (Ministry of Industry and Energy), CSN (The Spanish Nuclear Safety Council)	ENRESA, a state-owned company
Sweden	SFR	VLLW, LLW, ILW: classified by specified surface dose rate	NPP; research, etc.	Subsurface; Silo and cavern: 60 m beneath seabed	63 000	1988	16 963	Not necessary	SKI (Swedish Nuclear Power Inspectorate) SSI (Swedish Radiation Protection Institute)	SKB, a private company, owned by utilities. SFR is operated by the staff of the Forsmark Power Plant
Switzerland	LLW repository at Wellenberg	Short-lived low and intermediate-level waste	NPP; medicine, industry and research, decommissioning waste from NPP	Subsurface; Cavern: 500 m deep	200 000	2007	0	Not decided	HSK (Nuclear Safety Inspectorate)	GNW, owned mainly by NPP operators. The local community, local canton and the Federal Government can also become members
United Kingdom	Drigg	LLW: not exceeding 4 GBq/t alpha and 12 GBq/t beta-gamma	NPP, fuel cycle; research; radio-isotope production; hospital, etc.	Near surface; Trench and vault: 0 to 10 m deep	1 650 000 (Trenches: 850 000 Vaults: 800 000)	1959	Trenches have been filled. Vaults: 50 000	~ 100	The Environment Agency Nuclear Installations Inspectorate	BNFL, a state-owned company

3. COST COMPONENTS, DATA COLLECTION AND ANALYSIS METHODOLOGY

3.1 Cost components

In an ideal study, the costs of LLW disposal would be separately established for every facet of the disposal process, from the initial determination of the national need for the facility, through site development to its final closure and release after a period of institutional control. However, the current state of development of LLW disposal arrangements varies widely between NEA Member countries, from those that have long established repositories to others where repository development has yet to reach the construction phase. As a consequence, in many cases, reliance must out of necessity be placed on estimates rather than knowledge of incurred costs.

The total costs for low-level waste management include cost components associated with waste treatment, conditioning and packaging, interim storage and disposal. In general, waste treatment, conditioning and packaging are activities which can be undertaken directly by the waste producer, although in many countries centralised facilities are also provided. In contrast, disposal and, where a repository does not exist, interim storage are generally a centralised activity providing a service to the waste producers.

The direct disposal costs, that is, those associated with the repository, are discussed below and the associated pre-disposal costs are considered in Section 3.1.2. Increasingly, costs are also incurred to build public confidence and to gain and maintain acceptance of waste disposal activities and these are also addressed in Section 3.1.2.

3.1.1 Repository costs

The costs associated with waste repositories are possibly unique in that the identified timescales over which costs might be incurred extend over several hundred years as they cover site selection and development, construction, operation, closure and, ultimately, the ending of active institutional control. For some countries, institutional control periods of up to 300 years are envisaged.

For the purposes of this study the cost elements of a repository have been identified as planning and licensing, design and construction, operation, decommissioning, and closure and post-closure monitoring. Each of these five elements are discussed separately below.

Planning and Licensing activities encompass three main areas of costs: research and development, site screening and, finally, licensing.

- Research and development covers the activities necessary to permit the definition of a repository concept capable of meeting national requirements. It includes work undertaken to reduce the technical and financial risks associated with the concept to a stage where siting and design criteria can be specified with high confidence that these can be achieved in practice and that the resulting repository will comply with national waste management policy and associated safety criteria. It therefore includes the work necessary to underpin all aspects of the repository design and operation from establishing the siting criteria to specification of site closure requirements.

- Site screening and evaluation includes all costs associated with the siting programme which incorporates selection of potential locations from generic, topographical and geological data, followed by detailed geological and hydro-geological assessment of potential sites.

- Licensing costs encompass those incurred by the developer for the generation of assessments to confirm that protection of the public and the environment will meet national standards. These assessments include: environmental assessment; safety case for the receipt and disposal of waste packages during the operational phase; and post-closure safety assessments. Costs incurred by the regulatory bodies in the review of safety cases and ongoing monitoring and assessment of compliance are also included where these are charged directly to the repository operator in compliance with the "Polluter Pays Principle".

Design and construction costs include those associated with the detailed design and construction of the disposal facility and infrastructure, that is roads, service buildings, surface and segregated (potentially contaminated) drainage systems. They also include, where appropriate, visitor and public information facilities. They do not, however, include costs associated with the treatment and conditioning of facilities where these are located at the disposal site.

Operation costs incorporate all those associated with the physical handling and disposal of waste packages on an ongoing basis. Typically these include: waste receipt; monitoring, unloading and emplacement in the vault; backfilling between emplaced containers; and vault closure, including the provision of interim caps. Overpacking costs are not included unless otherwise explicitly mentioned (see section 3.1.2). Key supporting activities included in this element are:

- Quality Assurance/Quality Control (QA/QC) activities carried out by the disposal operator to ensure consignor compliance with the repository acceptance criteria relating to waste generation, treatment, conditioning and packaging, radionuclide assessment and transport;
- environmental monitoring activities to assess the environmental impact and integrity of the site;
- security; and
- overheads deriving from company, local and State charges.

Decommissioning and closure – key activities included are:

- emplacement of a final cap to provide long-term protection of the waste;
- establishment of a low maintenance drainage system for surface leachate arisings consistent with safety case requirements;
- decommissioning and removal of redundant operation facilities;

- environment and repository monitoring regime to permit assessment of repository condition;
- site maintenance and security.

Post-closure activity key costs are associated with site maintenance and security. The environmental and repository monitoring should be at a low level at this stage. Some cap remediation costs may also be included.

3.1.2 Additional LLW management costs

Additional costs associated with waste disposal include waste treatment, conditioning, packaging, interim storage and increasingly, economic incentives paid to local communities, though these costs are not included nor analysed in this study.

Waste treatment can be defined as activities which physically modify the waste to render it more amenable to conditioning and packaging for interim storage or disposal. For example, size reduction, incineration and compaction are methods which are widely practised.

Waste treatment entails additional capital and operating costs but the volume reduction leads to lower disposal charges. However, when practised on a large scale as part of the waste minimisation process, the lower disposal volumes generated have been found to translate into higher unit disposal charges. Nevertheless, given the wide range of treatable and non-treatable wastes normally encountered, it can be expected that, depending on the ratio of fixed to variable in the total waste management costs, waste treatment applied to suitable waste will be in many cases at least cost neutral.

Conditioning relates to the stabilisation or immobilisation of the containerised waste in a suitable matrix to provide mechanical strength, low inclusion of voids and high leach resistance in the final disposal package. Matrices employed include cement-based grout, bitumen and polymers.

Packaging containment of waste prior to disposal is required in all modern disposal facilities. Packaging specifications are primarily dictated by radionuclide containment and radiological protection criteria as established by the repository safety case and transport regulations. In general, therefore, the sophistication of the packaging required is related to the total activity of the radionuclides involved and can range from simple 200-litre steel drums to the stringently controlled manufacture of high integrity concrete and steel containers. National requirements for retrievability of the waste have also influenced packaging specifications in the form of overpacking of waste containers prior to emplacement. Such costs, where they occur, have been treated as additional costs except where they form an integral part of the disposal facilities' operating costs such as in Switzerland and at Olkiluoto in Finland.

Interim storage of low-level waste arisings is practised in a number of countries where a final repository for low-level waste has yet to be developed. In these circumstances waste treatment, conditioning and packaging of the waste need to take into account the particular radiological protection hazards associated with such storage and the fact that the packages will need to retain good structural integrity for a considerable time before they can be emplaced in the repository. In general, apart from the storage costs, interim storage does not introduce additional waste treatment, conditioning or packaging costs or constraints.

Economic incentives should not be used to gain public acceptance for a nuclear repository project or indeed any major industrial undertaking. Public acceptance is influenced by two main components, that is, safety concerns and the siting aspect (the NIMBY syndrome). It is important to dissociate the two when considering compensation for communities affected by the project. Ethically it is important that where financial compensation is paid it should not be regarded as a risk premium.

Compensating the siting region with financial incentives for services rendered in acceptance of the disposal facility whereby the whole nation can benefit from nuclear power and the use of radioisotopes, is seen by many countries both as equitable and a legitimate way to address the NIMBY syndrome. The level and nature of compensation/indemnity varies considerably from direct payments, job creation or infrastructure developments associated with, or in addition to, the main project development.

3.2 Data collection

3.2.1 Development of a questionnaire

The questionnaire was developed by the Secretariat, based on the Expert Group members' requirements for the analysis, and was distributed and collected through Expert Group members or through national representatives to the NDC for countries not represented in the group.

The responses to the questionnaire were reviewed at a subsequent meeting of the Expert Group. This resulted in the need for some clarifications and additional data. These were acquired by the Secretariat distributing requests for specific information to individual countries.

3.2.2 Summary of cost data provided for the study

Responses to the questionnaire were received from fifteen countries. More than one repository for LLW disposal is operating or planned in some countries, resulting in data for a total of nineteen repositories. These data are summarised in Table 3.2.

The costs used in this report were initially provided in national currency units as at 1 July 1995, and were converted into US dollars for comparison and analysis. Costs are basically expressed in real terms (i.e. undiscounted costs). Cost incurred in the past have been inflated, using national indices, to the reference date of 1 July 1995. Future costs are neither discounted nor inflated. Financing charges are not included.

Table 3.2 has been organised to divide the data into two general categories of repositories – near-surface repositories (nine repositories) and cavern-based/geological repositories (ten repositories). Inside each category, the data are also grouped into operating repositories (thirteen repositories) and planned repositories (six repositories, including the Korean project that was cancelled). The operating repositories may also be grouped into those established approximately twenty years ago or earlier (five repositories), and those established in the past decade (eight repositories).

3.2.3 Uncertainties and gaps in the data

The data provided in response to the questionnaire have been carefully examined and have been found extremely useful in describing the costs, as well as technical features of the repositories in operation and in advanced planning stages. Factors affecting the costs are analysed in detail in Chapter 4. The data needs to be treated with some caution, because although the definition and scope of the data are nominally the same for all repositories, the level of certainty does vary.

There is more uncertainty in data associated with repositories in the planning stage than for those in operation. Costs for planning and constructing operating facilities are known. There is also a base of experience for operating costs, although changes in the future are subject to some uncertainty. Closure and decommissioning costs will, for most of the repositories considered in this study, occur many years in the future. A fundamental factor contributing to uncertainty in costs, even for operating facilities, is the extended lifetime. Facilities are typically planned to operate for periods of thirty to forty years. However, there is a general trend to reduce volumes of waste produced, particularly at nuclear power plants, and therefore longer lifetimes may be expected.

With respect to gaps in the data, two different areas are observed. For the older facilities, established twenty or more years ago, costs for establishing the facilities are either not available, or not particularly relevant in terms of what those costs would be for establishing the same facility now. Simple escalation based upon indices of inflation does not capture the scope of the changes. The other area where there are substantial gaps in the data are costs for closure and decommissioning of support services and facilities, and for post-closure monitoring. In most cases, these have been established on a conceptual basis, although cost estimates have not necessarily been developed to the same level of detail as costs for construction and operation.

3.2.4 Consistency of data and basis for comparison and analyses of cost factors

Efforts were made to achieve consistency, both in the design of the questionnaire and through its review. For example, construction costs have been defined to include both initial construction and any subsequent expansion. It is not always easy to differentiate the latter from operating costs, particularly for near-surface repositories where construction of new vaults or disposal units is an ongoing process.

It is also important to recognise the large differences in scale among the repositories considered in this study with over three orders of magnitude in disposal volume capacity. This makes comparison of costs on an absolute basis questionable for many of the individual cost components.

As a result of the large differences in scale, two types of normalisation have been used in this study. The first considers costs per unit of volume (i.e. dollars per cubic metre of disposed waste). This provides a basis for comparison which is independent of the scale of the facility. It is important to recognise, however, that some components of the costs are fixed, or relatively invariant, with respect to volume. This type of analysis thus also provides an indication of the effects of facility capacity on unit costs. The analyses in Chapter 4 consider both total costs and costs per unit of volume.

The second type of normalisation considered in this report is the cost for low-level waste disposal normalised to the amount of electricity generated by nuclear power (i.e. dollars per TWh). The intent is not to produce a precise analysis, but rather an indication of the relative importance of the costs for low-level waste disposal in the total costs of electricity produced by nuclear generation. This type of analysis can be extended to levelised unit costs, both for the low-level waste disposal facility and the nuclear fuel cycle and reactor costs, bearing in mind that different time periods are generally involved for each. These types of analyses are considered in Chapter 5.

3.3 Methodology for data comparison

3.3.1 General background

In order to provide a meaningful comparison of the cost data for LLW repositories, these should be gathered in a consistent manner against a common set of definitions and criteria. Also, to simplify the comparison, the data has been converted from national currency unit as provided in the questionnaire by each participating country, into US$ of 1 July 1995. As international exchange rates fluctuate from time to time, they do not necessarily reflect the real price levels in each country and the converted costs in US dollars should be taken as indicative values. The costs in original national currency unit are shown in the country reports.

For the basic cost components defined in Section 3.1, the figures quoted for each repository are given in undiscounted money values, i.e. the costs are assumed to occur immediately without taking into account any time schedule. To consider immediate (or overnight) costs has the great advantage of not requiring assumptions, either on actual cash flows in time, or on discount rates to be used. It also greatly simplifies the presentation of the data; in the case of total operating costs, these can be readily calculated by multiplying the annual operating costs in US$/year by the total operating period defined for the repository.

A further reason for using undiscounted costs is that there are significant differences between participating countries in the time frames over which costs are to be incurred. In such cases the interpretation and comparison of discounted total costs becomes extremely difficult, if not impossible.

Discounted costs do have a part to play as an indication of the impact on electricity generation costs. To this end, indicative levelised unit costs are presented in Chapter 5.

3.3.2 Definition of factors used in cost data comparison

The main task within the scope of this report is to compare cost components in terms of both total capacity and per unit disposal, i.e. in US$, US$/m^3 or US$/year. The impact on electricity generation costs is expressed in US$/kWh. In calculating the cost per unit disposal, a key factor is obviously the waste volume in m^3. Several definitions are given below to help define this factor accurately.

Volume of waste (m^3) – conditioned waste "ready for disposal". In most cases, the volume of disposed drums or containers corresponds to the volume of waste defined as "ready for disposal". The volume of soil or mortar used to fill in the cavities surrounding the drums/containers is excluded as it varies considerably between repositories. Finnish, Spanish, and Swiss repositories use varying systems of overpacking. The resulting volume increases, which can be very substantial, are taken into account when measuring overall volumes, although the cost of overpacking itself is included in the case of Switzerland.

Total capacity of a repository (m^3) – total volume of waste, as defined above, which is to be accommodated in the repository. It should be noted that, in practice, the volumes of waste accepted may be constrained by radiological capacity considerations.

Annual delivery (m^3/year) – average volume of waste, as defined above, which will be disposed of annually in the repository. The volumes reported here are actual volumes as distinct from design capacity. The annual delivery is used as a basis for calculating unit operating costs ($\$/m^3$/year).

A second key factor in the analysis is the nature of the costs, whether fixed or variable. The different cost elements of the repositories have been extensively defined in Section 3.1 and the definitions of fixed and variable costs, as employed in this report, are as follows:

Fixed costs of a repository (US$) – costs which are, in a first approximation, independent of the total capacity, as defined above. Fixed costs are unavoidable. This means that they must be paid irrespective of the total capacity of waste in the repository.

Examples of fixed costs of a repository are the elements of research and development, the overheads deriving from the organisation set in place for operating the repository, and/or buildings such as administrative offices and visitors' centres. In practice, they are fixed only within certain limits. Beyond a certain capacity, the fixed costs will change as, for example, additional research, development programmes or a larger organisation are needed. If this complication is ignored, fixed cost per unit capacity, measured in $\$/m^3$, will decrease with increasing capacity. This is the economy of scale.

Variable costs of a repository (US$) – costs which depend on the total capacity and annual delivery of wastes, as defined above. The variable costs can be nearly proportional to the capacity. This is, however, not the general rule.

An example of variable costs in a near surface repository is the construction cost of repository vaults, since they are in a first approximation proportional to the total capacity. Generally, if near proportionality is assumed, variable cost per unit of capacity, measured in $\$/m^3$, can be considered to be constant. Purely proportional costs therefore manifest no economies of scale.

The distinction between fixed and variable costs is important in Chapter 4 in the discussion of technical factors affecting the unit costs of the repository. Most front-end costs are fixed. They include design studies and construction of basic infrastructures such as access roads and electricity/water supply, which largely do not depend on the capacity. As such, they manifest important economies of scale. By contrast, yearly operating costs have important contributions from both fixed and variable elements.

In theory an accurate identification of the fixed and variable contributions attached to each cost component of the repository would allow an understanding of the effects of economies of scale apparent in the comparison of country data. In practice, however, this information is not sufficiently detailed. As explained above, fixed costs may be modified beyond certain capacity thresholds and regarding operating costs, the truly variable part of workforce costs, for example, is in practice difficult to derive and in addition, may not necessarily be fully proportional to the capacity of the repository.

Table 3.2. **Summary of cost data for LLW repositories in US$**

Type	Status	Country	Location	Year operation started	Depth from ground (in metres)	Total capacity (m^3)	Total M$ (planning, licensing and construction)	Planning (M$)	Licensing (M$)
Near-surface repositories	**OP**	Australia	Mt. Walton (IWDF)	1992	<40	N.A.	1.3	0.7	
		Czech Republic	Dukovany	1994		18 520	6.9	0.1	0.1
		France	Aube	1992	–	1 000 000	391.6	23.7	2.9
		Hungary	Püspökszlágy	1976	6	5 000	4.5	N.A.	N.A.
		Japan	Rokkasho	1992	<20	80 000	673.8	105.2	(included)
		Spain	El Cabril	1993		100 000	126.6	14.2	7.8
		United Kingdom	Drigg	1959/1988	0-10	800 000 +850 000 (filled)	193.9	N.A.	N.A.
	PR	Belgium	Not specified			60 000	156.8	19.3	5.3
		Hungary	Udvari		5	40 000	47.0	5.9	1.4
Cavern-based and geological repositories	**Old Mines**	Czech Republic	Richard	1964	52	10 500	2.0	0.4	0
			Bratrství	1974	50	290	0.5	0.1	0
		Germany	Morsleben	1978	500	54 000	N.A.		
	OP	Finland	Olkiluoto	1992	70-100	8 432	35.6	9.4	0.9
			Loviisa	1998	120	5 400	26.9	9.4	
		Sweden	SFR	1988	60 from sea level	63 000	174.6	8.5	2.6
	PR	Germany	Konrad		1 000-1 300	650 000	1 836.0	775.6	
		Hungary	Üveghuta	Planned	100-150	40 000	66.6	6.9	2.4
		Korea		Cancelled		20 000	87.2		
		Switzerland	Wellenberg		500	200 000	955.7	347.5	

N.A. Data not available
OP Operating
PR Projected

Table 3.2. **Summary of Cost Data for LLW Repositories in US$**

CONSTRUCTION				OPERATION							
Civil (M$)	**Facilities (M$)**	**Total (M$)**	**Unit Cost ($/m^3)**	**Annual Cost (M$)**	**Annual Waste Delivery (m^3)**	**Unit Cost ($/m^3)**	**Institutional Control (M$)**	**Miscellaneous (M$)**	**Closure (M$)**	**Status**	**Country**
0.2	0.4	0.6	N.A.	0.1			0.06			**OP**	Australia
4.5	2.3	6.7	363.9	0.2	310	710	0.03				Czech Republic
		365.0	365.0	36.1	20 000	1 803	N.A.	N.A.	N.A.		France
		4.5	890.0	0.4	237	1 591	0.03	0.1			Hungary
474.0	94.6	568.6	7 107.0	N.A.			N.A.	86.3			Japan
62.7	41.9	104.6	1 046.4	7.5	5 000	1 500	0.82/a	65.9			Spain
171.6	22.3	193.9	242.4	11.0	12 000	917	0.14/a		398.5		United Kingdom
90.1	42.1	132.2	2 204.0	5.1	1 000	5 130	N.A.	28.1		**PR**	Belgium
8.0	12.7	39.7	993.3	2.8	1 143	2 458	0.06				Hungary
1.6	0.4	1.6	149.5	0.6	78	7 821		0.07		**Old Mines**	Czech Republic
0.4	0.2	0.4	1 379.3	0.1	10	12 000		0.01			
				21.6	4 300	5 023					Germany
19.0	6.3	25.3	2 999.3	0.4	224	1 607	N.A.		5.9	**OP**	Finland
12.9	4.7	17.6	3 251.9	N.A.			N.A.				
103.3	60.1	163.5	2 595.2	3.4	2 500	1 376	N.A.	0.08/a	13.8		Sweden
		1 060.4	1 631.4	49.1	16 250	3 024				**PR**	Germany
45.7	11.6	57.3	1 432.3	3.8	1 143	3 333		N.A.			Hungary
5.4	81.8	87.2	4 359.5		2 000			230.8			Korea
417.0	191.1	608.2	3 040.9	13.3	7 140	1 863		260.64	60.8		Switzerland

4. ANALYSIS OF FACTORS AFFECTING REPOSITORY COSTS

4.1 Introduction

As presented in the previous chapters, the costs of LLW disposal provided by Member countries present significant variations. An important factor which impacts on cost comparison, is the conversion of local currencies into US dollars. Differences are also due to uncertainties on cost data or assessments, in particular for projected repositories, or to discrepancies in cost breakdowns. However, these uncertainties notwithstanding, detailed analysis of disposal costs indicates that specific factors, both technical and non-technical, can be identified and significantly influence the costs.

In order to facilitate the comparison of disposal costs and identification of factors affecting costs, the repositories are classified into two major categories, near-surface and cavern-based/geological, and each category into two sub-categories, operational and projected. Special attention is given to old repositories, either cavern-based/geological (in abandoned mines) or near-surface type, whose construction costs are not comparable to newer facilities.

In this chapter, the cost elements considered are those described in Section 3.1.1. Technical factors affecting costs are examined in terms of each of these cost elements. Non-technical factors are considered on a more general basis, since variations are expected to occur on a less systematic basis than for technical factors.

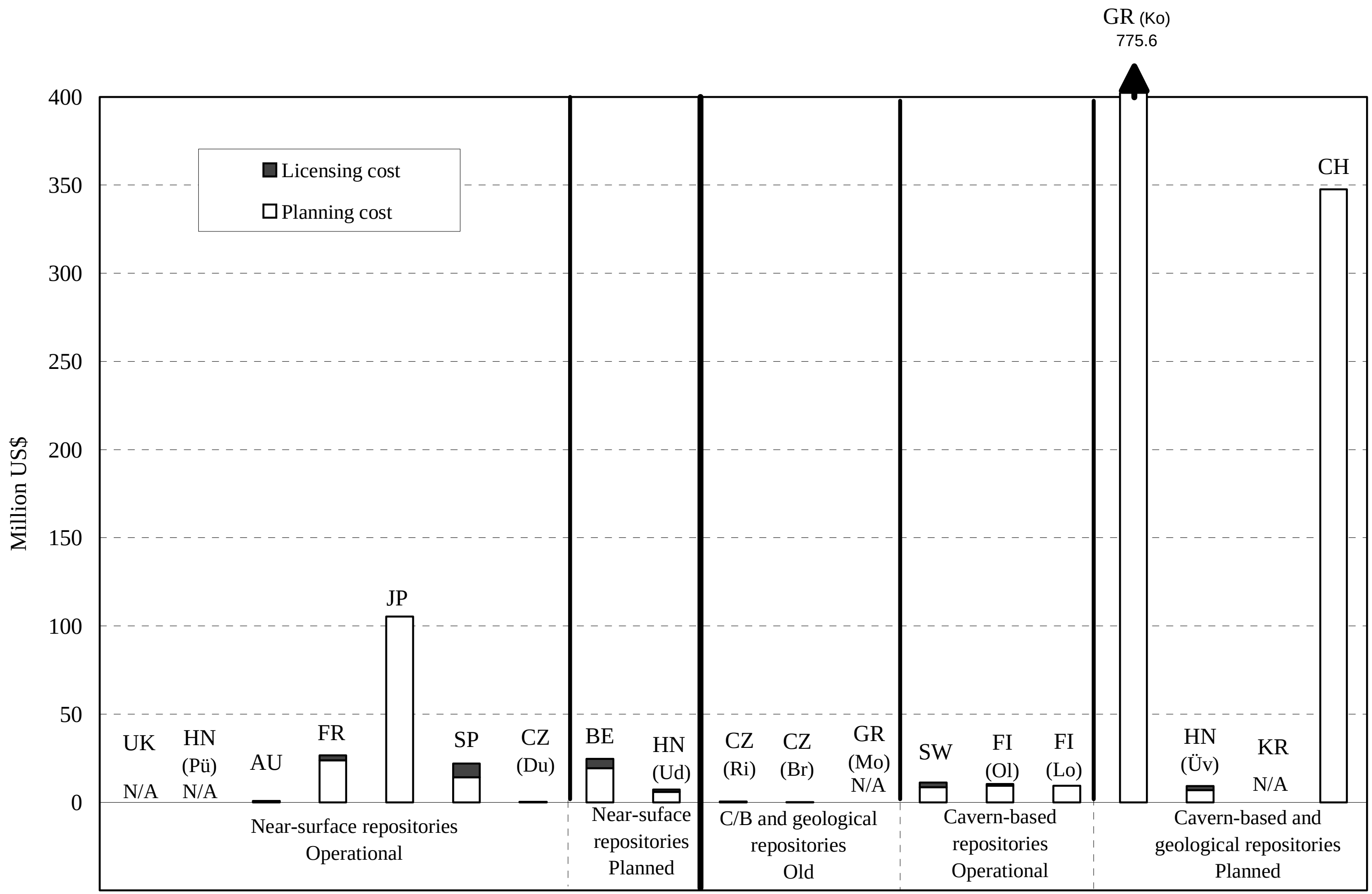
4.2 Technical factors affecting costs

4.2.1 Planning and licensing

Planning and licensing costs represent, in general, a small percentage of the total costs for LLW disposal. The cost information provided by Member countries is shown in Figure 4.2.1. The data are subdivided between near-surface repositories and cavern-based/geological repositories. Within each grouping, the data are plotted from oldest (to the left) to most recent, with data for projected repositories furthest to the right.

Several general observations follow from the data. Costs were particularly low, or were not incurred, or were not separately recorded for older repositories. This extends both to near-surface repositories [e.g. Hungary (Püspökszlágy) and United Kindgom (Drigg)], and to cavern-based/geological repositories established in old mines [e.g. Czech Republic (Bratrství and Richard) and Germany (Morsleben)]. Even if data were available, it is questionable whether they would be applicable today in light of the major changes in socio-political factors which affect planning costs for recent and projected repositories.

Figure 4.2.1 **Planning and licensing costs versus repository type**



With the exceptions of Germany (Konrad), Switzerland and, to a lesser extent, Japan, the planning and licensing costs shown in Figure 4.2.1 are all roughly comparable. That is, the costs do not exhibit any particular trend with type of repository (near-surface or cavern-based/geological). With the exceptions noted above, there also does not appear to be any particular trend between recently established operational repositories and projected repositories.

Although the cost data show that the planning and licensing costs are roughly equivalent for all repositories, except Germany (Konrad) and Switzerland, some technical factors may impact on the planning costs, for example:

- the level of geological investigation required for site screening and characterisation;
- the number of candidate sites to investigate;
- the repository environment, on a virgin site or near an existing industrial facility, which may require more or less infrastructure;
- the requirements for R&D work on waste conditioning and/or disposal to demonstrate the feasibility and safety of the project.

In Germany (Konrad) and Switzerland, socio-political factors linked to the regulatory process or to public acceptance have considerably increased the licensing lead-time and generated much higher expenditures. Changes in the laws or regulations on nuclear safety, waste management or other relevant matters may also cause delays in the planning/licensing process and consequently increase costs. These non-technical factors are further discussed in section 4.3.

4.2.2 Construction

The repository capacity is expected to be one of the major factors which impacts on construction costs. Total construction costs will obviously increase with capacity. Another factor is the annual volume of delivered waste. Even if there is an obvious relationship between the two parameters, the level of annual delivery dictates the design and size of part of the infrastructure, such as the waste receiving building and the number of disposal modules required for the start of operations. The transportation infrastructure and equipment are also partly related to the level of annual deliveries.

Figures 4.2.2(a) and 4.2.2(b) show construction costs versus repository capacity. Construction costs for capacity added (or planned to be added) after the start of operations are included. In Figure 4.2.2(a), total costs are grouped for near-surface repositories and for cavern-based/geological ones, ranked by size from left to right within each group. Figure 4.2.2(b) shows the same data, total costs versus capacity, on logarithmic scales. Logarithmic scales are needed since both the costs and capacities range well over two orders of magnitude. With few exceptions, the costs increase monotonically with capacity. Some facilities, such as the Richard and Bratrství repositories in the Czech Republic, show very low costs due to the fact that waste is disposed of in worked out mines. Old mines used as cavern-based/geological repositories have a very low construction cost unless they require significant rehabilitation and upgrading caused by increasing requirements of the licensing procedure, such as the Konrad mine in Germany. Costs for the Japanese repository are also higher than would be inferred from the volume ranking. One contributing factor is that the currency exchange rate used in this study for Japan was at a historically high level relative to the US currency, about 40 per cent higher than in June 1997.

Figure 4.2.2 (a) **Construction costs versus capacity**

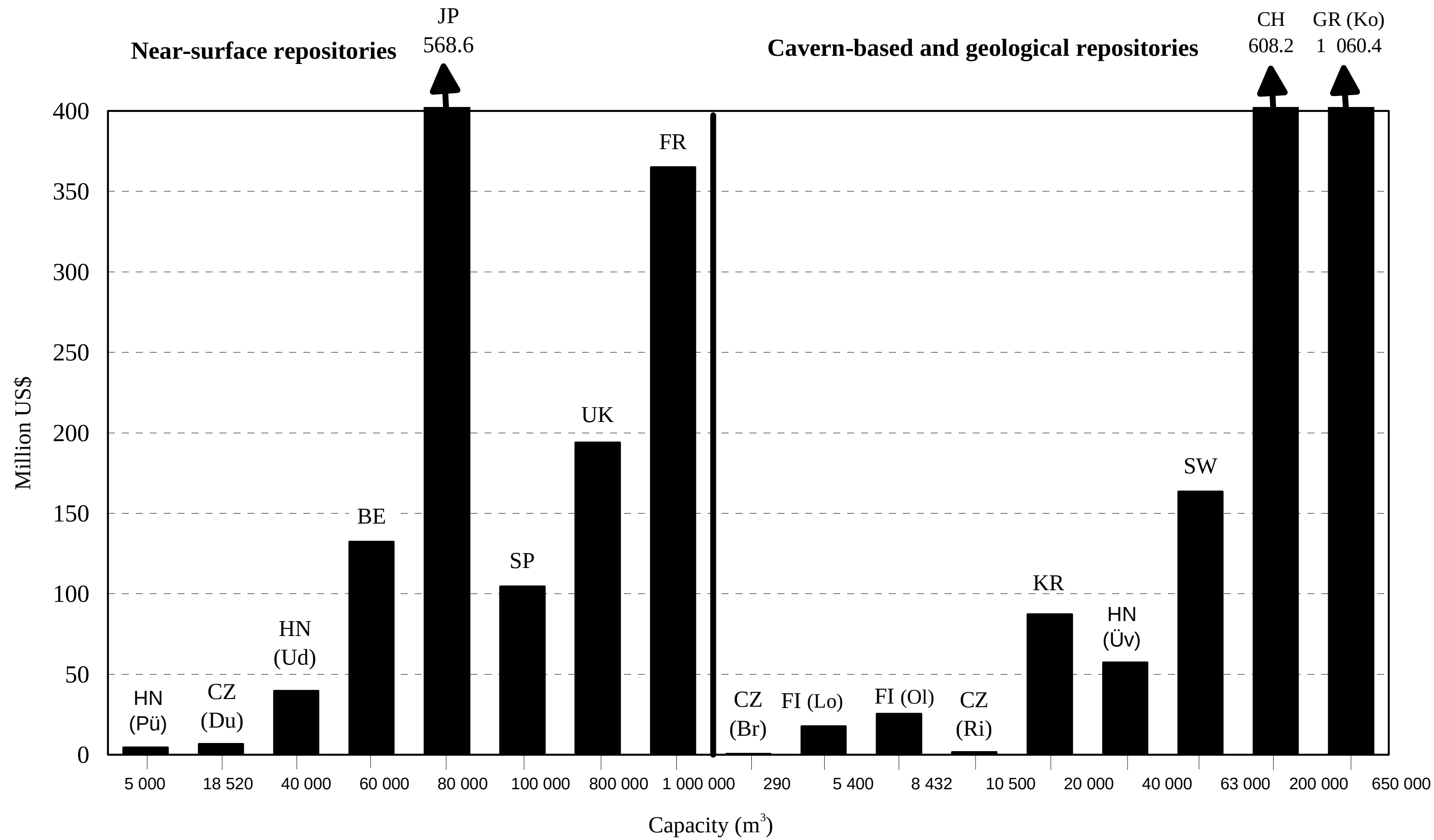
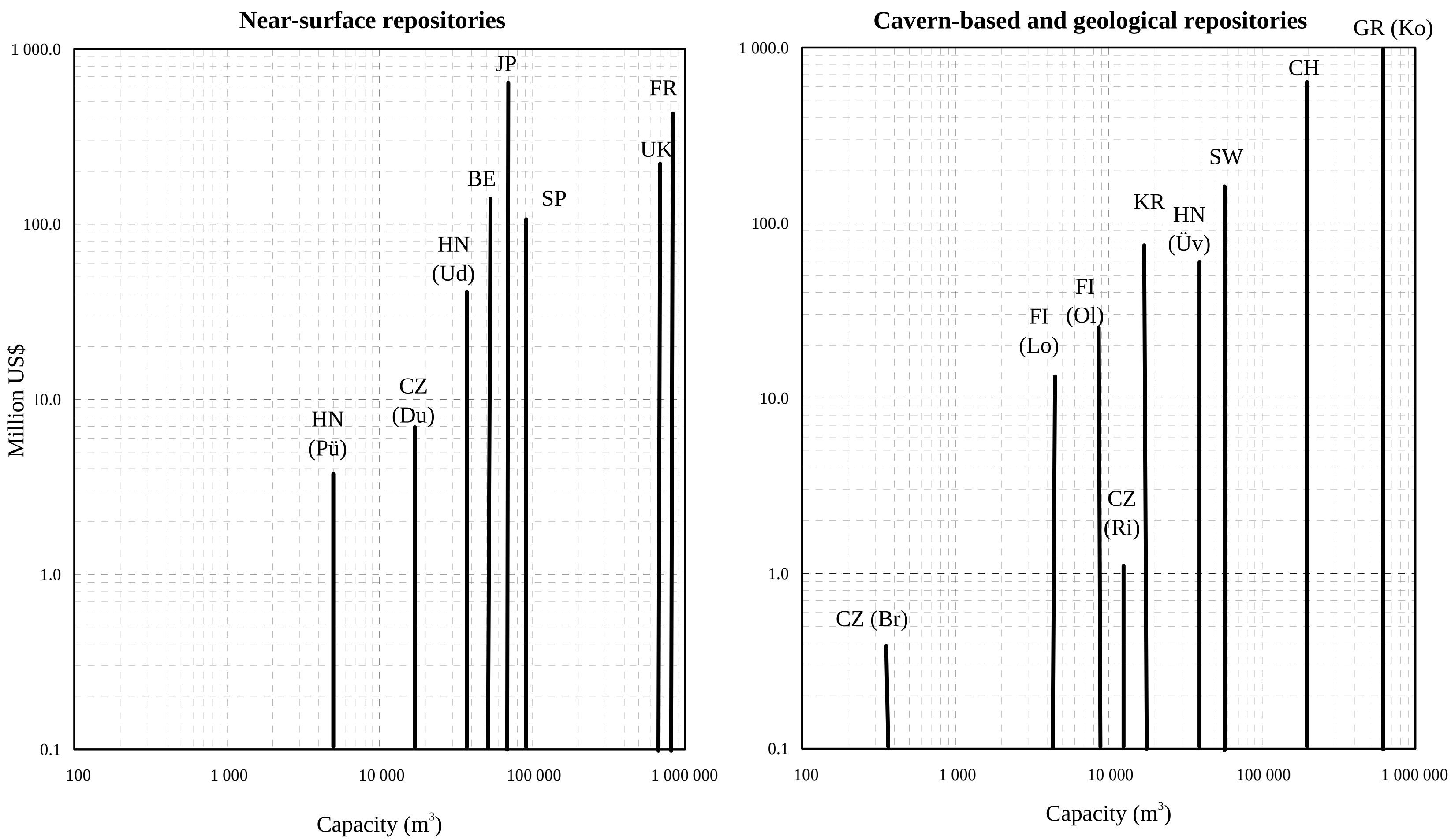


Figure 4.2.2 (b) **Construction costs versus capacity**



Although a major part of the construction costs is closely related to the repository capacity and to the waste volumes delivered each year, there is also a part of these costs which is largely independent of size. For example, site water collection and monitoring systems, environmental monitoring, equipment laboratories, and auxiliary facilities such as administrative and technical buildings, visitors' centres, restaurants, security buildings, roadways and parking lots, etc. are all largely independent of facility volume. These fixed elements allow economies of scale to be realised.

Scale effects are shown in Figures 4.2.2(c) and 4.2.2(d), with the former showing total costs versus capacity, and the latter showing normalised costs ($/m^3) versus capacity. For these figures, all data have been plotted with different symbols used to illustrate different types of repositories. A scale effect is clearly present for near-surface repositories, where the unit construction costs per m^3 are significantly lower for the large size repositories, such as the Drigg facility in the United Kingdom and the Centre de l'Aube facility in France where capacities approach 1 000 000 m^3. A similar scale effect is not shown for the cavern-based facilities; the unit costs for the Swiss facility (Wellenberg) and German facility (Konrad) are not substantially different from the much lower capacity facilities in Finland (Loviisa and Olkiluoto) and Sweden (SFR). It should be noted, however, that German facilities are at a much greater depth, as required by the national policy and regulations. Costs increase with repository depth.

Some of the infrastructure costs may be avoided if the repository is constructed on or near an existing industrial site. Both the Finnish and Swedish facilities are built close to nuclear power plants and benefit from being able to share part of the adjacent infrastructure and services. Repositories built at virgin sites therefore show higher expenditures related to site preparation, transportation systems (roads, railways) and utilities.

The data in Figure 4.2.2(d) have been broadly grouped into three categories. The outlined area shows a group of repositories towards the centre of the cost range, taking into account the effect of scale on unit costs. Unit costs for the German and Swiss cavern facilities lie above this range. As noted previously, these facilities are at greater depth, and also have been affected by socio-political and regulatory factors. Costs shown for the Japanese facility have been affected by changes in currency exchange rate, and also appear to be affected by other technical and non-technical factors specific to this facility. There is also a group of four facilities with unit costs which lie below the central range. Two of these were established in old mines, and a third was established many years ago, so that much lower costs are to be expected. In addition, all of these facilities are in the Czech Republic and Hungary and it is uncertain whether the currency exchange rates used for this study adequately reflect historical costs for these countries and as a consequence under-estimate the amount of goods and services which could be purchased locally for a given expenditure.

The differing impacts of scale, site and facility specific features, plus difficulties inherent to conversion into a common currency, make it difficult to draw precise conclusions about the relative construction costs of near-surface and cavern-based/geological repositories. To the extent that comparisons can be made, cavern-based repositories appear somewhat more expensive. For example, projected costs have been provided by Hungary for both a near-surface and a cavern-based repository, one of which is expected to be built. For the same capacity of 40 000 m^3, the construction costs for the mined cavern (Üveghuta) are projected to be twice those of the near-surface facility (Udvari). In the 60 000 to 100 000 m^3 capacity range, unit construction costs for the SFR facility in Sweden are higher than for the projected facility in Belgium and the El Cabril facility in Spain, after allowing for scale effects.

Figure 4.2.2 (c) **Total construction costs versus capacity**

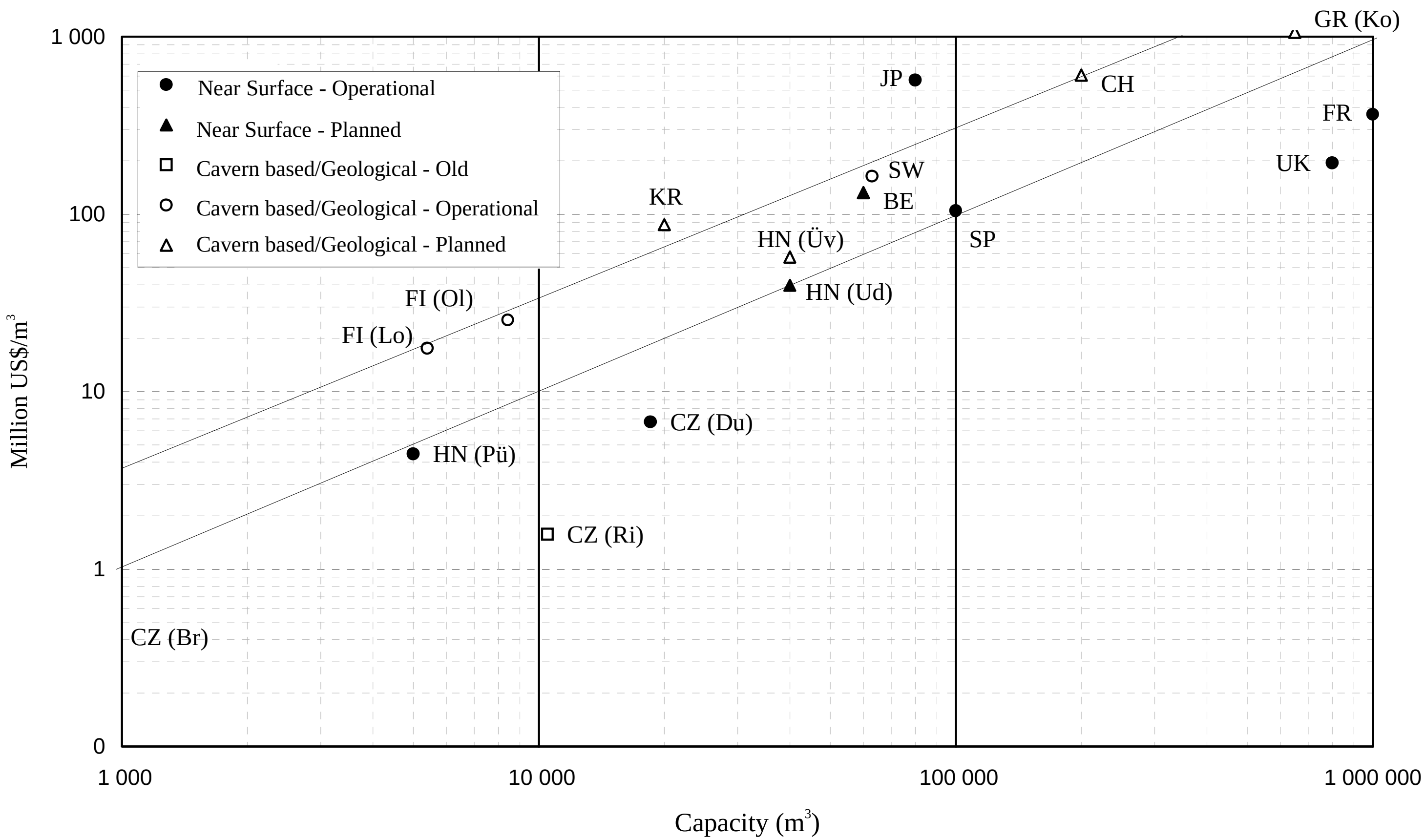
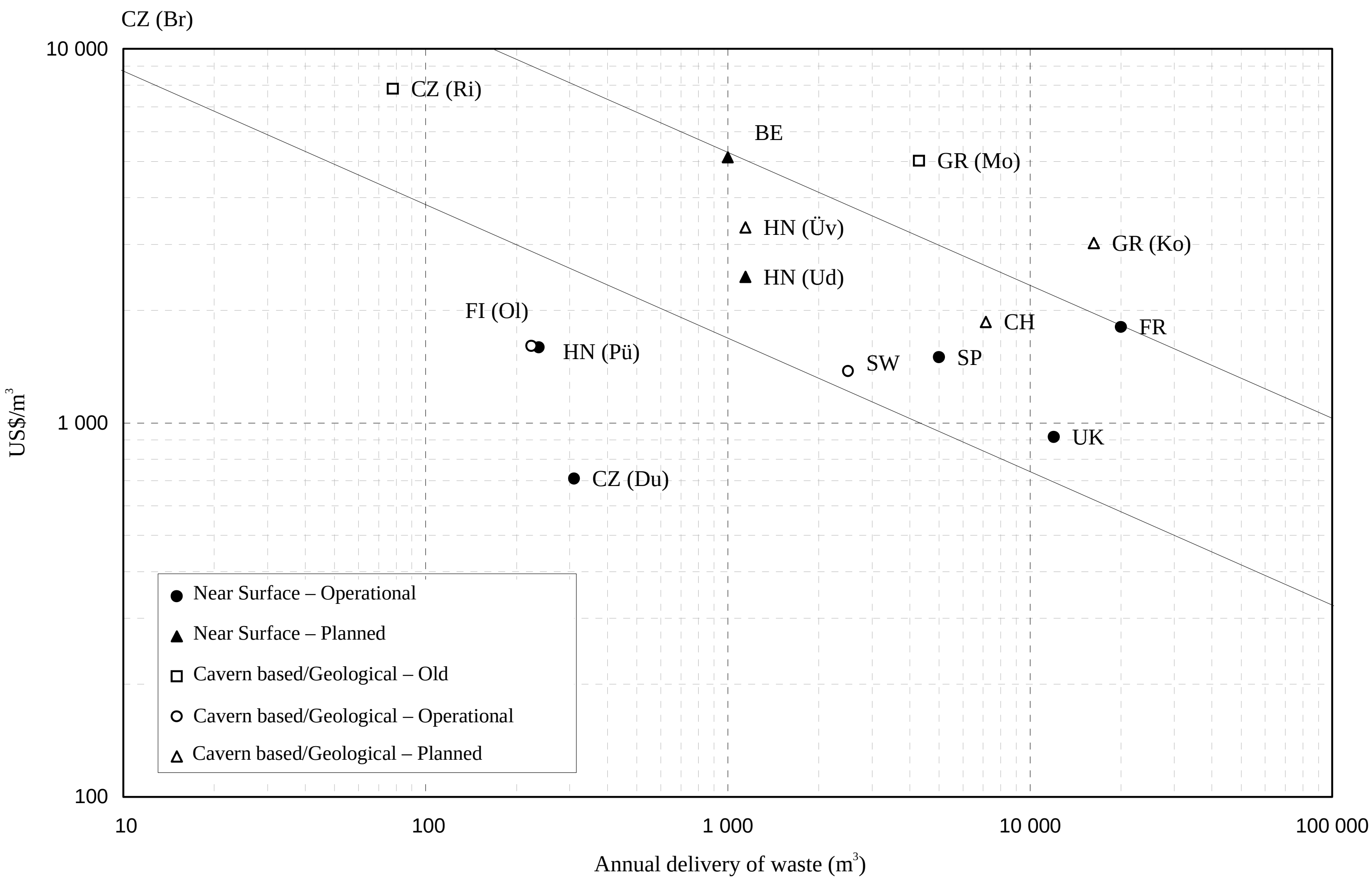


Figure 4.2.2 (d) **Specific construction costs versus capacity**



As for any nuclear facility, engineering costs often represent a significant fraction of the construction cost (20 per cent or more). Other costs associated with construction, such as project management, equipment procurement, commissioning and quality control, also represent a significant part. The engineering, and consequently the construction costs, can be reduced by using proven technology instead of prototypes. As an example, many of the features of the French disposal system demonstrated at the Centre de l'Aube facility, were used in the design and construction of the El Cabril repository in Spain. This transfer of technology resulted in lower engineering costs.

4.2.3 Operation

As shown in Figures 4.2.3(a) and 4.2.3(b), operating costs of near-surface and cavern-based/geological repositories do not present significant differences. The operating costs can be split into fixed costs which are not related to the quantity of waste delivered to the repository and variable costs which are proportional to the annual delivery volume.

The fixed costs include site environmental monitoring and other services, site maintenance, security and protection, administration and headquarters costs, taxes, insurance, etc.

The variable costs are directly related to the level of on-site activities. They include labour costs for waste transportation, handling and disposal, filling the disposal structures, inspection of waste packages, radioactivity monitoring, maintenance and repairs, etc., as well as supplies and materials procurement.

Cost data provided by Member countries indicate that the split between fixed costs and variable costs varies from country to country. Moreover, the scope of operating costs is not the same for all countries. For example, when a disposal facility is located near the site of a nuclear power plant, part of the operating costs, such as administration, environmental protection or security costs, may be supported by or at least shared with the nearby plant. There is a positive impact on costs from such co-locations as demonstrated by the SFR repository in Sweden or the Olkiluoto facility in Finland.

As shown in Figure 4.2.3(c), an economy of scale clearly appears for near-surface repositories. There is a similar tendency for cavern based/geological facilities. The trend in Figure 4.2.3(c) is somewhat affected by the high operating costs of the German facilities and the French facility, and the low operating costs of one of each of the facilities in the Czech Republic, Finland and Hungary.

Other factors which may affect operating costs are the level of automation and standardisation of waste packages.

These two factors tend to impact on site workforce size, contributing to an increase in productivity and consequently reducing the labour cost. The automation of waste handling and disposal is also a key parameter in radiation protection, as demonstrated in several recent disposal facilities. Increased automation may, however, entail some increase in maintenance costs.

Figure 4.2.3 (a) **Operating costs versus repository type**

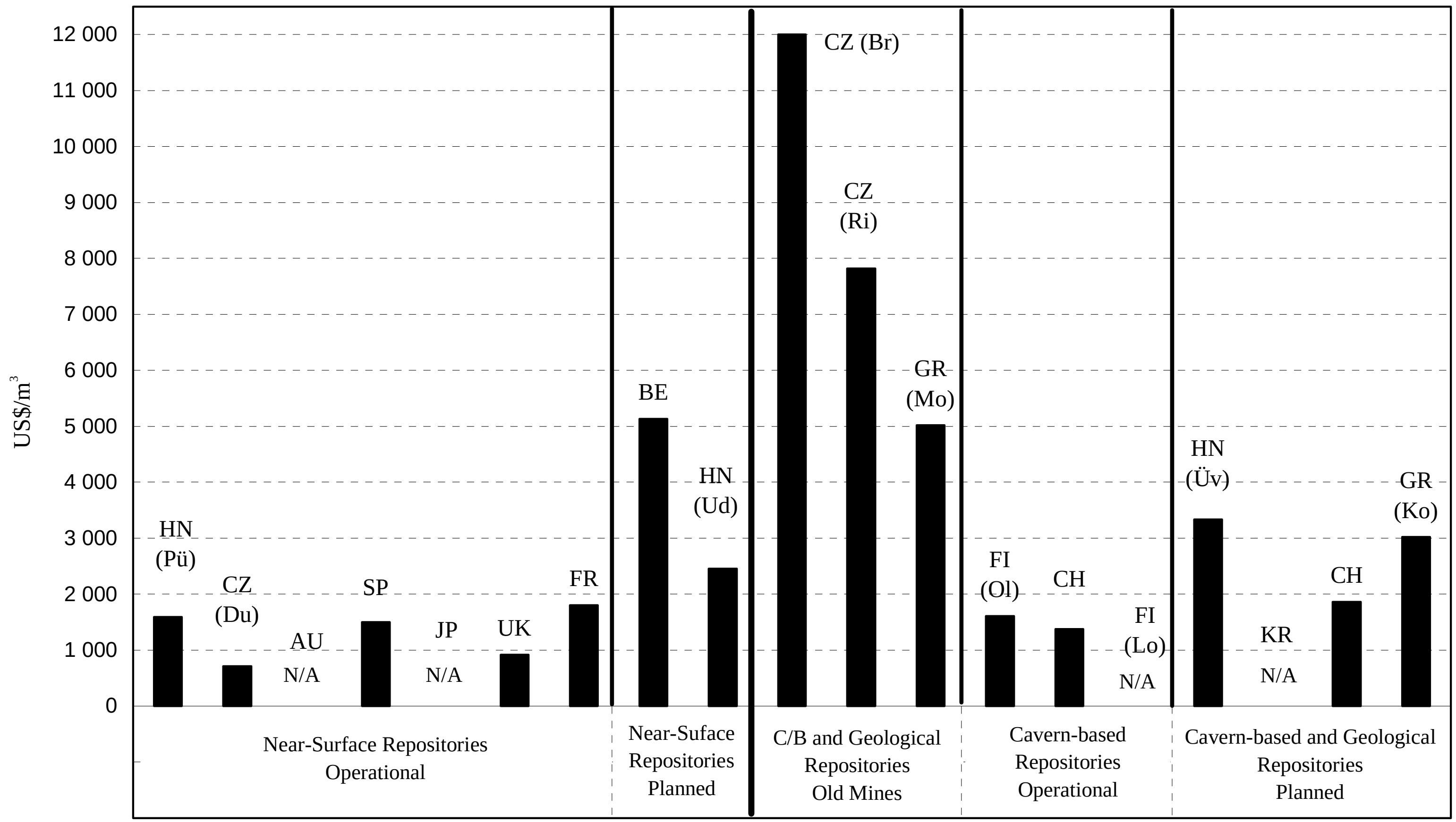


Figure 4.2.3 (b) **Operating costs versus annual delivery**

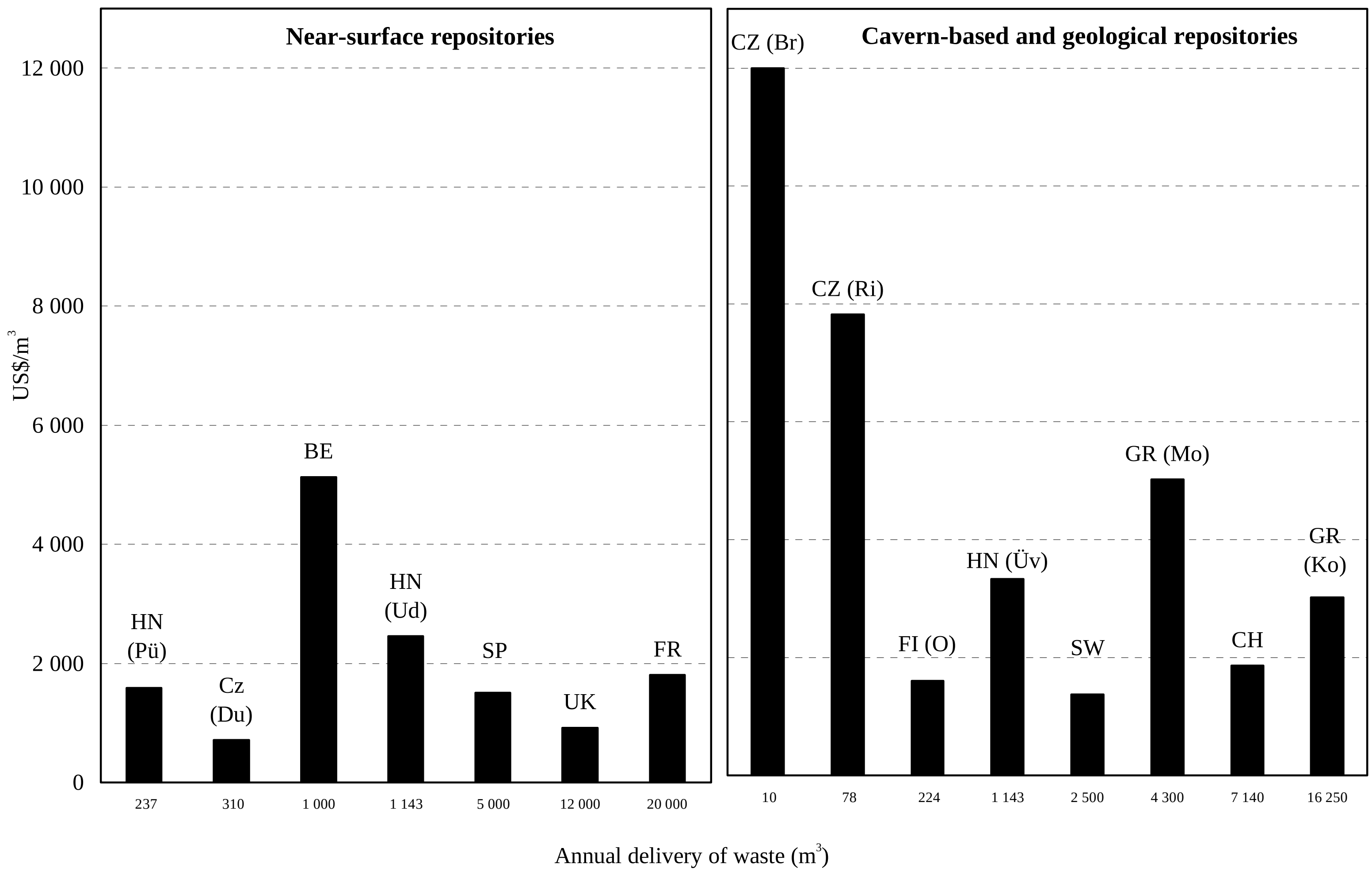
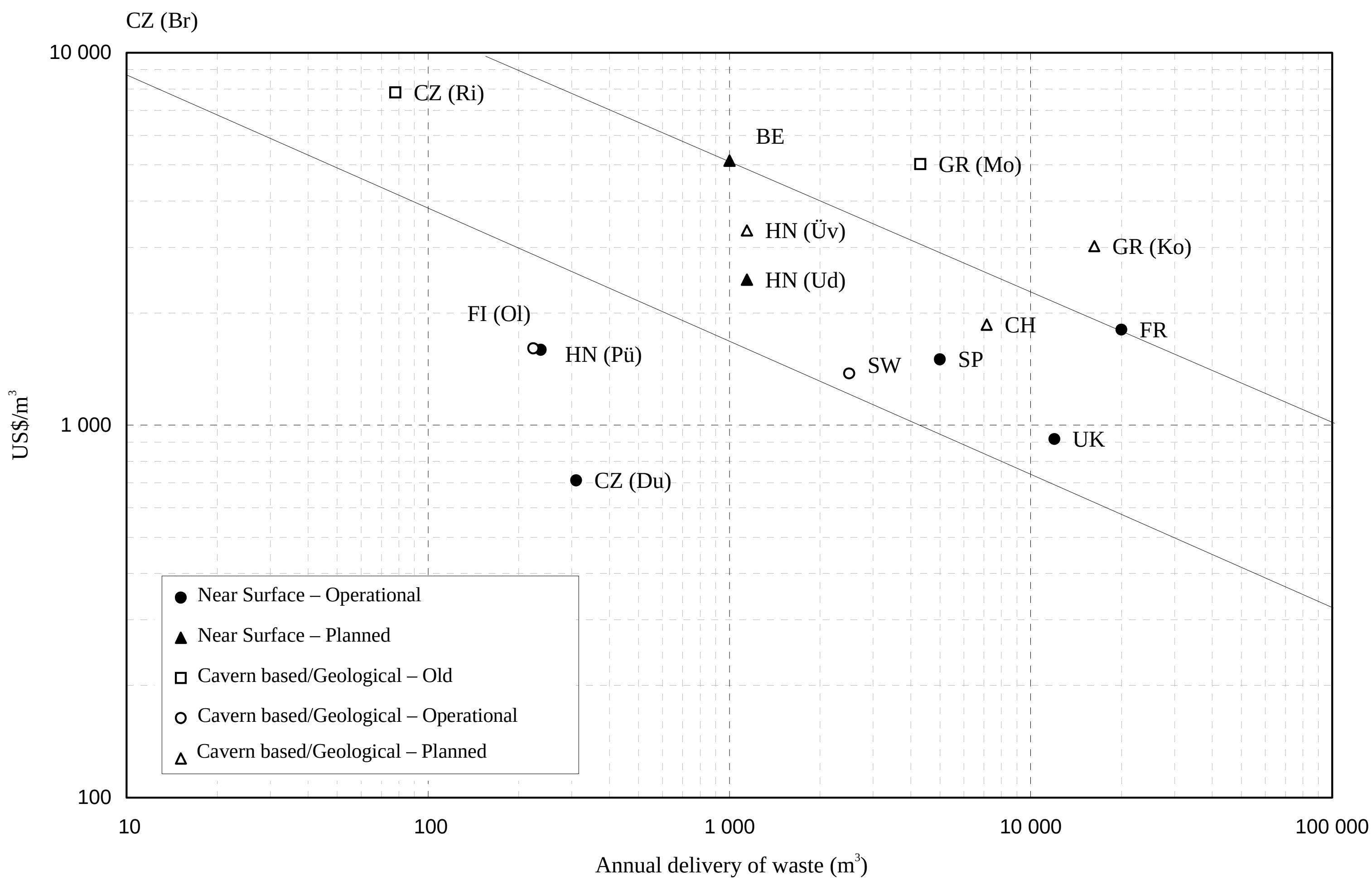


Figure 4.2.3 (c) **Operating costs versus annual delivery**



The extent of site environmental programmes (sediment sampling and analysis; water, air, groundwater and surface water monitoring; and radiation measurements) may have a significant impact on operating costs. Again, radioactive waste disposal facilities located on or nearby NPP sites benefit from this proximity by establishing common programmes and sharing resources.

4.2.4 Decommissioning and closure

There is little actual experience of closure of LLW disposal facilities and decommissioning of support facilities and services. For most facilities, plans are at the conceptual stage. There is consequently less data available than is the case for the costs for establishing and operating facilities. There is also greater uncertainty in the available data. These considerations notwithstanding, it is clear that decommissioning and closure costs are a relatively small fraction of the total lifetime costs for a disposal facility, probably in the order of 5 to 10 per cent, e.g. France (l'Aube), Hungary (Udvari), Sweden (SFR), Finland (Olkiluoto). Costs for the United Kingdom (Drigg) facility are estimated to be a higher fraction (approximately 15 per cent); however, these include cover costs for the historical trenches as well as for the current design of vaults. Closure costs for old mines, which were originally converted to disposal facilities without significant upgrading, will also be a relatively higher fraction of the total costs, since initial construction costs are very low or non-existent.

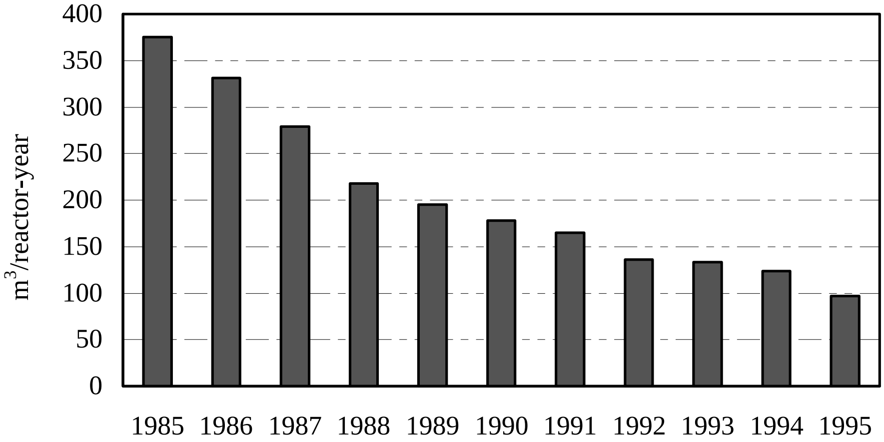
4.2.5 Post-closure activities

The major factor affecting the cost of post-closure activities is the type of facility. Generally, institutional controls are not planned for cavern-based facilities. For near-surface facilities, institutional control periods of 100 to 300 years are commonly planned, depending on the time required for the radioactivity in the disposed waste to decay to a level where the radiological hazards are insignificant. Annual costs for post-closure monitoring, inspection and administration are, however, expected to be low. They are typically projected to be a few per cent of the annual costs incurred during the facility operating period. Discounting also affects the costs substantially when applied over periods of 100 to 300 years.

4.2.6 LLW volume produced by nuclear power generation

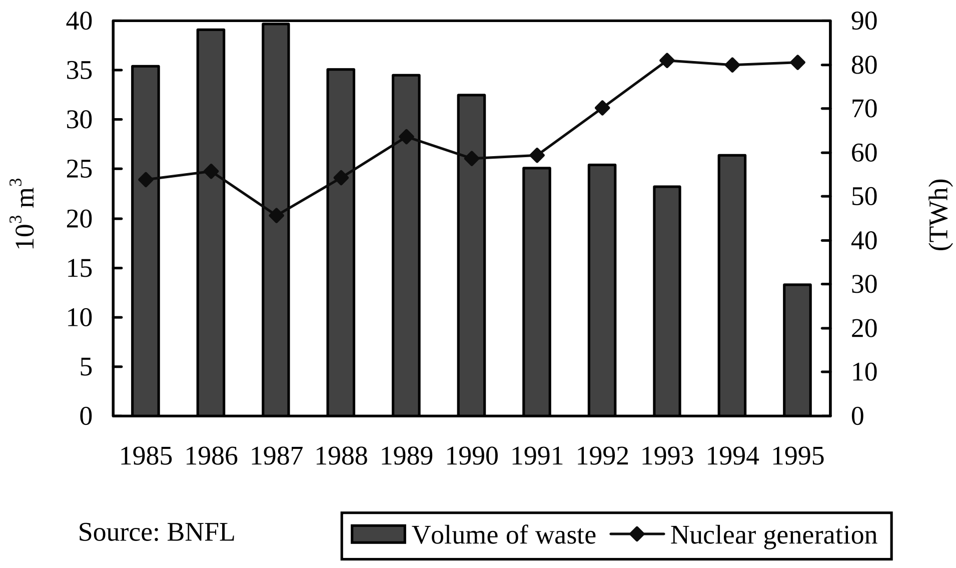
A supplementary factor that needs to be addressed when considering costs is the trend in volumes of waste produced by nuclear power generation. Once a repository is established, a significant proportion of the costs is fixed and consequently unit costs are sensitive to changes in volumes of waste arising. A noticeable trend is that the volumes of LLW for disposal are decreasing as a result of waste minimisation measures and wider use of incineration and compaction systems, including super-compaction. This is illustrated in Figures 4.2.6 (a) and (b) which show the downward trend in French nuclear power plant radioactive waste production. Figure 4.2.6 (b) shows corresponding reductions in total LLW arisings in the United Kingdom. As indicated in section 3.1.2, it should also be noted that the downward trend in volumes of LLW is accompanied by additional costs from the volume reduction processes.[8] The impact of waste minimisation and volume reduction processes therefore needs to be analysed when considering the totality of LLW disposal costs.

Figure 4.2.6 (a) **Volume of conditioned radioactive waste from French nuclear power plants**



Source: EdF

Figure 4.2.6 (b) **Disposal to Drigg (United Kingdom)**



Source: BNFL

4.3 Non-technical factors affecting costs

A range of non-technical factors affects disposal costs. Although many are commonly experienced, the extent to which they apply may vary markedly amongst different countries. Some factors which depend on national policy are specific to particular countries. Non-technical factors are thus discussed in terms of the individual factors, with examples used to highlight their importance in determining overall costs for disposal.

4.3.1 Socio-political factors

Public acceptance and political decisions are the major factors which may significantly affect the disposal costs. Changes in waste management policies or difficulties with public acceptance have been experienced in almost every country. Information provided by Germany (Konrad) and Switzerland demonstrate how socio-political factors significantly increase the planning and construction costs. Although not specifically included in this study, substantial costs have resulted from the protracted site selection processes followed in recent years by a number of efforts to establish new LLW disposal facilities in the United States.

Economic incentives to communities selected, or volunteering, to host controversial facilities, such as LLW disposal facilities, are an example of a social-political decision. Economic incentives such as local community development aids represent a significant fraction of the cost in some countries. In addition, expenditures for communication, public relations and visitors' reception facilities contribute to integrating the waste management activity into the local environment and therefore can be considered a social cost.

Once a radioactive waste disposal facility has started operation, socio-political factors have normally less influence than during the planning and construction phases. However, the operation of an existing repository may still become a political issue, and external pressure may result in stricter regulations and consequently changes to operating conditions and costs.

4.3.2 Regulatory requirements

Regulatory requirements normally define the national standards to protect the public and the environment. They may also impose or recommend the safety cases which should be examined and the methodology to assess the environmental impact of the facility. The disposal system which results from these considerations may have more or less sophisticated engineered structures, more or less stringent specifications on acceptable waste forms and packages, and more or less extensive site screening and evaluation processes.

The evolution of international recommendations and national regulation which results in enhanced protection of the public and the environment is illustrated by the changes in radioactive waste disposal concepts or techniques. Thus, at the Drigg facility in the United Kingdom, concrete structures have replaced engineered trenches. In France, sturdy concrete vaults at the Centre de l'Aube repository replace the former monoliths and tumuli of the Centre de la Manche facility. These improvements, which have indisputably contributed to increased environmental protection, also result in higher construction costs.

During the design construction phases, before the facility is licensed, modifications may be required by the regulatory or licensing authority. These changes result either from new or additional requirements, or more simply from different interpretation of regulations. Any modification during construction will impact unfavourably on the cost and possibly delay start-up.

Regulatory costs are also incurred on an ongoing basis during operation of the facility. These include costs not only for maintaining compliance with licence conditions but, in many cases, costs to secure approval for changes to facility operations or equipment, or for accepting additional waste types.

In addition to costs incurred directly by the facility operator, regulatory agencies in some countries also recover their costs from the operator.

4.3.3 Taxes and insurance

Taxes are a significant component of the operation costs in some countries while, in others, the disposal costs are almost tax-free.

Insurance fees vary greatly from country to country. Due to the specific risk linked to environmental protection for this type of activity, the insurance rates may have a significant impact on the cost of operation.

4.3.4 Finance

The main financial factor affecting the comparison of undiscounted costs used in the present report arises from the conversion of the national currencies into US$.

The conversion from national currency units to constant US$ of 1 July 1995 does not eliminate the discrepancies in purchasing power between countries. One US$ is not worth the same everywhere as there are large differences in wages, tax levels, etc. These discrepancies are further increased by the different inflation rates experienced in NEA Member countries over the time-frames considered. Last but not least, the comparisons are complicated by the continuously shifting exchange rates.

A factor of moderate importance is the differences in accounting or financing practices employed. In some countries loans must be contracted to finance the basic infrastructures. When no money is charged to the future users before the repository becomes operational then the costs recorded in the accounts of the organisation in charge of the repository will include the interest charges accrued during the construction of the basic infrastructures.

4.3.5 Timing

The most important impact of timing on costs is due to the discounting practices used. A delay in the operating schedule of the repository will increase the interest expected to be earned on the funds provided and the expected increase reflects the choice of discount rate. Timing and discount rates are important factors in the financing of the repository. However, they are not part of the scope of the report, except for the impact on the levelised generation costs of electricity discussed in Chapter 6.

Delayed development may have other impacts on the undiscounted costs of the repository which are difficult to assess precisely. A potential benefit might be expected as a result of technological progress reducing costs. The gathering of experience and the learning from the operation of other newly developed facilities could also bring some decrease in actual costs.

A drawback of delayed development of a repository is to be found in increased costs resulting from the waste having to be kept in interim storage over longer period of time. In addition, an upward cost drift could be caused by tightening regulations or more demanding environmental rules as time unfolds.

4.3.6 Land acquisition and cost of services

In addition to costs for infrastructure at the disposal facility, significant costs may be associated with purchase of land for the site and, depending on its location relative to existing services, providing services such as roads/rail, electricity, water and others.

5. IMPACT ON NUCLEAR ELECTRICITY GENERATION COSTS

5.1 Introduction

The costs surveyed and analysed in the previous chapters provide a detailed breakdown for the different stages of repository development from planning to closure, to enable each element such as construction cost to be analysed and compared among different repositories in Member countries. The previous chapter did not therefore analyse relationships in terms of the total costs of repositories nor provide an overall view on the share of LLW repository costs in electricity generation costs.

Although an overall comparison may raise legitimate arguments on the extent to which the different elements of costs are comparable, this chapter tries to give some reference analyses to show overall status. This chapter therefore deals with total cost and also shows the share of LLW repository costs in the total costs of nuclear electricity generation in a sample reference calculation.

In Section 5.2, the simple summation of normalised cost elements is analysed from planning through licensing, construction, operation and up to closure to provide costs per unit volume of waste. In Section 5.3, the timing of when costs are incurred is also taken into account using an appropriate discount rate and sample calculations in order to get the levelised cost of LLW repositories associated with electricity generation.

Care is needed when interpreting the analysis in this chapter. The following points, in particular, should be noted. There is a considerable gap between the timing of expenses associated with electricity generation, LLW generation and its disposal, with wide variations between different countries. Another point is that LLW volumes generated for each unit of electricity, and which are used in the sample reference calculations, are currently decreasing rapidly, though some additional costs are envisaged to be incurred in achieving the reductions (see Section 4.2.6). The assumptions used in the model calculation may therefore change from time to time so caution is required in extrapolating relative costs.

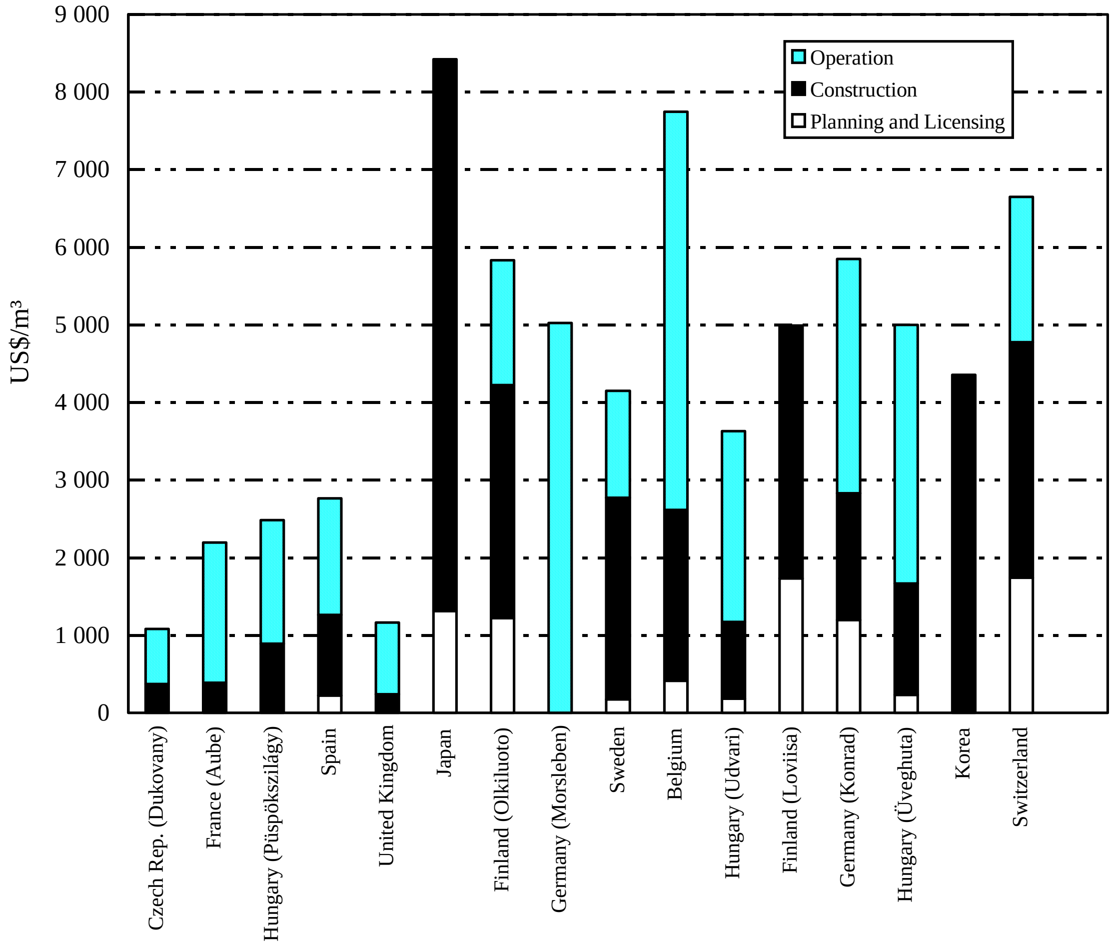
As briefly shown in Chapter 3, full costs incurred in LLW management are not necessarily covered by this study, i.e., full costs also include sorting the radioactive waste, interim storage at the power generation sites and/or dedicated storage sites, treatment of the LLW, transport of the LLW to the repository and so on, all of which are not within the scope of this study. It should be noted that these extra pre-disposal costs are not at all negligible but rather are comparable to the LLW disposal costs.

5.2 Cost per unit volume – simple summation of cost elements

In this section, a simple summation of cost elements of the LLW repository is examined. The aim is to provide a reference figure and show the relative importance of various cost elements using a simple calculation which does not consider the different timings of expenditures and ignores discounting. As the timing of expenditures is not taken into account here, the figures derived should not be quoted for financial liability considerations nor for price setting.

In deriving the relative cost per unit volume, planning, licensing, construction and closure costs are taken to arise instantaneously at 1995 undiscounted money values, even through it is recognised that the duration of the activities may be some years. The values quoted by Member countries for these elements are total costs and hence, the unit cost was derived by dividing total cost by total capacity. In the questionnaire, however, operating costs have been recorded as annual costs and therefore in this case the annual disposal volumes have been employed on equivalent operational cost per unit volume. The previous NEA study on high-level waste disposal cost[9] took a similar assumption as described above when comparing the cost estimations of Member countries, i.e. it compared a simple aggregation of normalised but undiscounted cost elements. The timing of the costs in the development of the LLW repository will be further discussed in the next section.

Figure 5.1 **Summation of cost elements (undiscounted)**



Post-closure monitoring was not taken into account in this section. All near-surface repositories will be monitored and access controlled for a certain period after closure. The duration of post-closure monitoring and access control has not yet been definitely fixed in many countries. The anticipated duration would, however, typically be between 100 and 300 years. The long duration of post-closure monitoring compared to other elements of cost mean that a simple summation which included this element would distort the overall estimate of LLW repository cost, hence its exclusion.

Figure 5.1 shows the result of the summation. It should be noted that some countries, such as Japan and Korea, do not include operating costs and a larger group of countries do not include closure costs because it is not yet estimated with adequate certainty. Two small Czech repositories are also not included here because their current annual reception of LLW is too low to obtain a reasonable estimate of annual operating costs, i.e. the reported annual operation cost is far from typical.

5.3 Cost per kWh

In the previous section, the comparative weight and impact of each cost element were examined by simply adding up the normalised costs in US dollars per cubic metre of LLW. In this section these data will be examined as part of the total nuclear electricity generation cost.

A linear relationship was assumed here, for all the countries, between the volume of the LLW produced by nuclear electricity generation and the amount of electricity generated. Although there is a time lag between the waste produced by electricity generation and its disposal, and there is also a downward trend in the volume of LLW per unit of electricity, a simple assumption is made for a model calculation. Since country questionnaires provided little information on actual volumes of LLW per unit of electricity, a single reference volume is used for all the countries. LLW and VLLW arising from decommissioning were not taken into account here.

In the case of HLW disposal cost,[9] fairly simple linear relationships between electricity generation and HLW production were readily observed no matter which fuel cycle route is chosen (once-through or reprocessing). On the contrary, LLW is produced from various activities related to nuclear power plant operation, and hence, there is no firm linkage between the volume of LLW and electricity generated.

The volume of LLW per unit of electricity varied in the country questionnaires, partly because of different waste treatment approaches and partly because of the different scope of wastes covered. Whereas Belgium reported the volume of LLW per unit of electricity generated as 10 m^3/TWh (excluding decommissioning waste), Spain reported 94 m^3/TWh (including decommissioning waste). The UK indicated lifetime LLW arisings at 35 m^3/TWh, although current arisings from PWR, AGR and Magnox reactors are very much lower than this value, reflecting improved waste minimisation and volume reduction practices. An IAEA study[8] showed 130 m^3/GWe/year (capacity factor 0.8) as a reference case for conditioned LLW from nuclear power plant operation, which is equivalent to 18.6 m^3/TWh.

If we take this IAEA reference figure for LLW arisings per unit electricity, the costs of LLW repositories calculated from the data given in the previous section range from 0.02 to 0.17 US mills per kilowatt hour*. Those costs are a very small fraction of the total levelised (i.e. discounted) electricity generation cost, which, for example, could range between 40-80 US mills/kWh.[10] When discounted, the costs of LLW repositories would be a smaller part of generation costs, taking into account long-term operation, and the conclusion would remain true. These figures are also much lower than other elements of fuel cycle costs, such as high-level waste management costs.

5.4 Sample calculation for discounted costs

The previous section gave a simple summation of elements of LLW repository costs without considering the time periods over which costs are incurred. Although this approach provides a useful indication of overall LLW repository cost, the detailed picture requires discounting and levelisation of the costs to be considered. The following sample calculations illustrate how discounted and levelised costs might be used to provide a more comprehensive view.

The scope of this study does not include financial liabilities. Financial liabilities have been studied previously by the NEA.[2]

The impact of discounting is evident when considering the costs of long-term monitoring (100 to 300 years) following closure of the repository. For a discount rate of 3 per cent per annum, the capitalised value of a perpetual care fund for 300 years is 33 times the annual cost, a small fraction of the 300 times the annual cost implied when discounting is ignored.

Detailed discussion on discount rate and levelised costs can be found in other publications by the NEA.[10,11,12,13] Essential points extracted from these publications are presented below.

Discount rate

In simple terms, if money can earn r (fraction per annum) in real terms, US$ 10 today will become US$ 10 $(1+r)^t$ in t years time. Conversely if US$ 10 is to be spent in t years time then the sum that needs to be set aside today is US$ 10 $(1+r)^{-t}$.

Cost comparisons can be very sensitive to the value of discount rate adopted; for example, a fund worth US$ 1 000 in 50 years time will have a present day value of US$ 1 000, US$ 87, and US$ 8.5 if discounted at 0 per cent, 5 per cent and 10 per cent per annum, respectively.

The discount rate can be viewed as the opportunity cost of capital to the investors, which may be determined by market forces or by government policy. In the NEA's economic studies on nuclear power, 5 per cent per annum in real terms has, in most cases, been favoured as a base discount rate.

* Undiscounted, simple summation of cost elements; some countries do not include all cost elements. One US mill is one thousandth of a US dollar.

Levelised cost

Since various costs are incurred at different times, and often beyond the time duration of electricity generation, constant-money levelised lifetime cost per kWh of electricity is normally used to standardise costs. The levelised cost is an average cost in constant-money value which, if charged for each unit of electricity produced, would exactly repay all the capital and operating costs. This assumption, that the electricity sales recover the costs involved, leads to the formulae below.

The total present-day value of disposal costs equals:

$$\sum_t [(c_t+m_t+d_t) / (1+r)^t]$$

c_t	=	Investment expenditures in the year year t
m_t	=	Operation and maintenance expenditures in the year t
d_t	=	Closure expenditure in the year t
r	=	Discount rate in fraction per annum
$\sum_t$		is the summation over the lifetime of the repository from planning to post-closure monitoring

The total present-day value of electricity generated equals:

$$\sum_t e_t / (1+r)^t$$

e_t	=	Electricity generation in the year t
$\sum_t$		is the summation over the operation lifetime of the power plant

The lifetime levelised cost of disposal per unit of electricity generated equals:

$$\sum_t [(c_t+m_t+d_t) / (1+r)^t] / \sum_t [e_t / (1+r)^t]$$

Although the above discussion on levelised cost was originally developed in the study of the whole nuclear fuel cycle and its comparison with other energy sources, the methodology can be applied to illustrate the impact of LLW disposal on the total cost of electricity generation.

Sample calculation

The above formulae can be used to provide an order of magnitude calculation showing the relationship between nuclear power programmes and LLW repository costs. The data used below are indicative rather than actual costs.

Assumptions used in the sample calculation

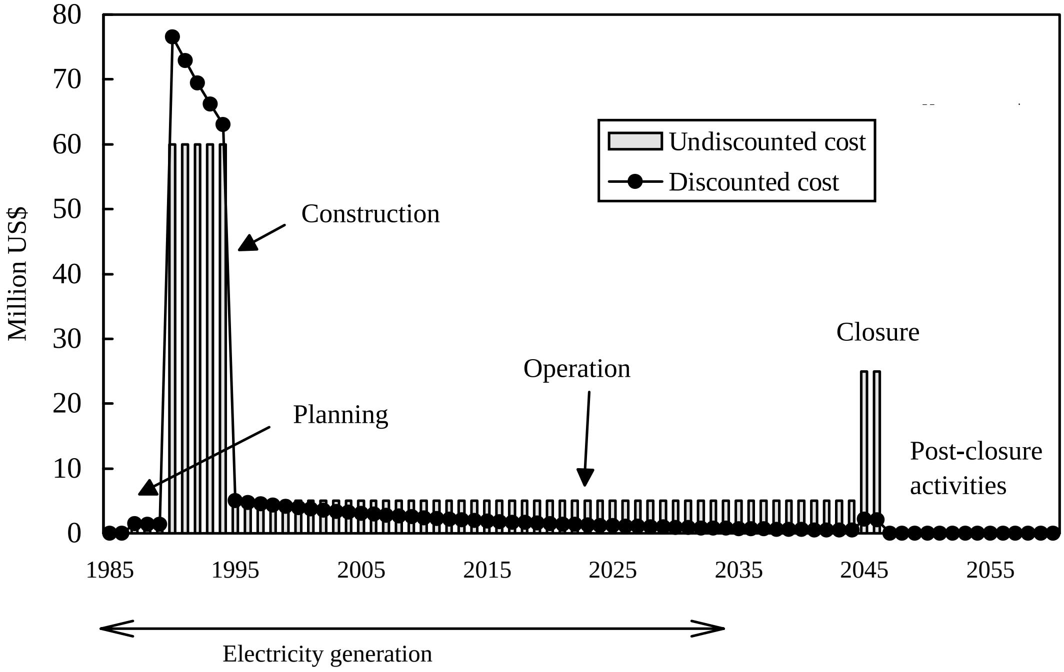
Nuclear power programme	
Number of reactors	20 NPPs of 1 GWe reactor (building 2 reactors per year for 10 years; starting in 1985)
Plant life of NPP	40 years
Load factor	0.8 (0.7 for the first year of operation)
LLW repository	
Type	Near surface
Capacity	200 000 m^3
Planning and licensing	US$ 1 million p.a. (3 years)
Construction	US$ 200 million (5 years); completed in 1995 (the base year)
Operation	US$ 15 million p.a. (50 years)
Closure	US$ 50 million (2 years)
Post-closure activities	US$ 0.5 million (300 years)
Others	
Discount rate	5 per cent p.a.
Base date	January 1995

Results of the calculation

Total discounted cost (million US$ of 1995)	528.92
Total discounted electricity to 1995 (TWh)	3 311.90
Levelised unit cost of LLW repository (US mill of 1995/kWh)	0.16

Figure 5.3 shows undiscounted and discounted costs arising each year. The post-closure monitoring is quoted only for the initial part of the operation (the remainder is omitted because of the scale).

Figure 5.3 **Discounted and undiscounted LLW repository costs**



The sensitivity of LLW repository costs per kWh to different discount rates is illustrated below:

DISCOUNT RATE	Reference (5%)	High (10%)	Low (3%)
Total discounted cost in 1995 (million US$)	528.92	438.53	634.88
Total electricity discounted to 1995 (TWh)	3 311.9	2 612.5	3 919.5
Levelised unit cost of LLW repository (US mill of 1995/kWh)	0.160	0.168	0.162

One of the implications derived from this exercise is that the future cost incurred by the post-closure monitoring is not a major part of the total levelised cost due to the discounting effect over the long periods involved. For example, the difference in total costs between a 100-year and a 300-year post-closure monitoring is in the order of one thousandth of one per cent of the total cost. Another finding shown in section 5.3, is that because of the impact of discounting, the operating cost is not such a large proportion of the total cost as was implied by the simple summation of the cost elements. It should be noted that these findings are influenced by the discount rate adopted.

6. CONCLUSION

This report analysed the factors which affect the costs of low-level radioactive waste repositories in NEA Member countries, drawing from data on 13 repositories in operation and 6 planned. All of them are planned, built and operated in accordance with stringent national safety regulations that conform with internationally accepted standards.

National drivers and procedures for disposal system selection

National drivers and procedures for the selection of disposal sites and methods vary among Member countries. They have a large effect on the repository costs. Country-specific details are given in Chapter 2 and Annex 2 of the report. The disposal system selected – near-surface vault types, cavern types or deeper geological types – is determined by each country's geological conditions, public acceptance in the region and overall policy approach. Public acceptance issues have become increasingly important, leading to the view that progress in developing a repository is given higher priority than minimising cost. Costs are nevertheless very important and their further reduction is needed, while ensuring that safety standards are maintained. A trend in reducing waste volumes has been pointed out in the study. Reduction of the waste volume may not always decrease the total cost since elements of the waste reduction process itself, such as waste sorting and compacting, increases the costs of waste management.

Are costs comparable between countries? What are the difficulties?

Repositories surveyed in this study are divided into two groups: operated and planned. The reported costs of planned repositories are based on estimations, and are more uncertain than those of operating repositories. Furthermore, the simple exchange rate conversion used in the analysis does not make costs directly comparable, in particular when considering eastern European countries and those with anomalies in their exchange rates at the time of comparison, such as Japan. The difficulty of analysis is made even more complex by the different technical and non-technical features of the repositories. However, the aim of the report is not to find out which repository has the lowest or highest costs, but rather to analyse factors affecting costs. Indeed, direct comparison without full recognition of the national context should not be made.

The repositories surveyed meet a wide range of requirements in terms of waste accepted for disposal. Some repositories only accept low-level waste whereas others accept intermediate-level waste as well. The definition of waste categories accepted also differs between countries. The origin of LLW varies from medical use to nuclear fuel cycle activities including power generation, decommissioning and fuel reprocessing. This variation gives less uniformity in LLW than in HLW. These factors, though not all analysed in detail in the report, affect the comparability of costs between repositories.

Socio-political and regulatory factors are not necessarily represented in the cost data, but they certainly affect the cost of the repositories. Similarly, timing of construction affects the costs, given that the later the construction is performed, the more stringent the requirement on repositories becomes in order to meet social goals and to benefit from advanced technologies. These factors are by their very nature difficult to quantify and make the comparison harder.

In the main comparisons provided, costs have been given in undiscounted money value terms. However, real financial costs should take discounting into account, particularly when the costs are associated with long-term operation and monitoring, and when compared to other costs in nuclear power generation. An illustrative calculation of discounted costs is provided in Chapter 5.

How applicable are past experiences to the future? Some specific comparisons and findings

Historically, planning and licensing costs tended to account for only a small fraction of overall costs, whereas today they can sometimes represent a significant portion of the whole. The German and Swiss cases, in particular, showed fairly large costs for planning and licensing procedures. This may be attributed to socio-political factors in those countries and, should these factors become more widespread, further increases in the planning costs of future repositories would be implied.

A scale effect has been found, in particular in construction costs of near-surface repositories. Unit construction costs, i.e. total construction costs divided by capacity (volume) of the repository, have been found to be lower for repositories with larger capacities. This is to be expected as much of the cost is associated with facilities and infrastructures which are largely independent of the size of the repositories.

The construction costs of near-surface repositories are lower than those of cavern-type repositories. This general trend is illustrated by the two planned repositories in Hungary. However, a simple comparison between near-surface, vault-type repositories and cavern-type repositories should be avoided, owing to their different cost structures. For example, in some countries, post-closure monitoring is not required for cavern-type repositories.

The costs of repositories which are adjacent to existing facilities such as nuclear power plants, as is the case in Sweden and Finland, are lower than others due to cost sharing. However, it is recognised that, especially for new repositories, site selection is not necessarily decided on economic grounds, but on public acceptance considerations.

Operating costs are not affected by size to the same extent as construction costs although again, certain parts of the operating costs such as administration, security and radioactivity monitoring costs are fixed (i.e. not proportional to the volume of waste delivered annually).

Since the repositories in Member countries have not yet experienced a complete closure process, the cost of closing the repositories could not be analysed comprehensively in the study. Some countries have given estimated closure costs. France effectively "capped" La Manche repository three years ago, but detailed figures are not yet available. No real experience has been gained yet on the institutional control period.

LLW repository costs, as defined in this study, appear to be a small fraction of total electricity generation costs. The costs provided in the report are not discounted costs; discounting would further reduce their share in total generation costs. An illustrative sample calculation that takes discounting into account confirms the small impact of LLW disposal costs on generation costs.

Finally, other cost components such as sorting, treatment, conditioning and transport that were not considered in this study are not negligible. These cost elements are part of the true cost of overall low-level radioactive waste management. They have not been studied since the waste repository is the main focus of the report, and these activities are generally not undertaken at the repository. An overall waste management cost study, which may well incorporate costs related to high-level waste and decommissioning waste management, would be of value as a follow-up to this study.

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CURRENCY EXCHANGE RATES

(in national currency units per US$)

COUNTRY (currency abbreviation)	As of 1 July 1995
Australia (AUD)	1.410
Belgium (BEF)	28.470
Czech Republic (CZK)	26.122
Finland (FIM)	4.270
France (FRF)	4.853
Germany (DEM)	1.390
Hungary (HUF)	125.840
Japan (JPY)	84.600
Korea (KRW)	758.100
Spain (ESP)	121.370
Sweden (SEK)	7.269
Switzerland (CHF)	1.15
United Kingdom (GBP)	0.63

GLOSSARY

Near-surface repositories

Repositories with or without engineered barriers where disposed wastes are buried on or just below ground level. Although the IAEA’s classification identifies repositories at tens of metres depth as “near-surface repositories”, such as Sweden’s SFR, this study differentiates these types from shallow burial repositories to allow greater differentiation of costs. (See section 2.1.2).

Cavern-based repositories (sub-surface repositories)

Repositories which are placed at greater depth compared to near-surface repositories; typically tens of meters depth. Cavern-based repositories can be specially excavated caverns or disused mines, such as abandoned iron ore mines and salt domes with appropriate additional engineering works, if necessary. Cavern-based repositories can in general accept a wider range of radioactive waste than near-surface facilities. (See section 2.1.3).

Geological repositories

Repositories which are placed in deep geological formations, at depths of at least a few hundred metres. In general, deep geological disposal is required for HLW and long-lived and/or alpha emitting waste; however, in certain countries, it is required that all types of radioactive waste should be disposed in geological repositories. (See section 2.1.4).

Overpacking

Overpacking is an additional package for conditioned waste to improve handling and/or protection. Concrete or steel containers are typically used for overpacking. As overpacking increases the volume of waste significantly, careful definition of waste volume is required to ensure consistency when calculating the cost per volume of waste (unit costs). (See **Capacity** below).

Capacity

The capacity of the repository is the total volume of waste that can be accommodated excluding overpacking and backfilling by concrete, soil etc. Only in the case of Switzerland is overpacking taken into account.

The reception capacity is the volume of waste which the repository can accept per year or per day. It can be determined by the capacity of handling facilities, examination facilities, etc. Maximum design reception capacity is generally larger than the actual volumes accepted by the repository, and the latter is used in calculating the unit operating cost ($/$m^3$).

Fixed cost

A cost which is not proportional to variations in key parameters. For example, costs of infrastructure such as access roads and services are quite often independent of the size of the repository; and costs of certain services such as administration and maintenance are independent of the actual volume of waste received. (See section 3.3.2).

Variable cost

A cost which is proportional to variations in key parameters, such as the capacity. For example, the construction cost of vaults of near-surface repositories is proportional to the number of cells or trenches.

Each element of the costs, such as planning, licensing and construction costs, is described in Section 3.1.

LIST OF UNITS AND ABBREVIATIONS

Bq	Becquerel, SI unit of radioactivity
BWR	Boiling water reactor
Ci	Curie, old unit of radioactivity equal to 3.7 x 10^{10} Bq (37 GBq)
GWe	Gigawatt (= 10^9 watts) electric
Gy	Gray, the SI unit of absorbed dose equal, for ionising radiation, to 1 joule of radiant energy absorbed in 1 kg of material (1 Gy = 1 J/kg)
HLW	High-level radioactive waste
ILW	Intermediate-level radioactive waste
kWh	Kilowatt hour (= 10^3 watt hour)
LILW	Low and intermediate-level radioactive waste
LLW	Low-level radioactive waste
manSv	Man Sievert, unit of collective dose
NIMBY	Not in my back yard
p.a.	Per annum
PWR	Pressurised water reactor
R	Röntgen
R&D	Research and development
rem	A unit of dose equivalent equal to 0.01 Sv
RI	Radioisotope
Sv	Sievert, unit of dose equivalent
TWh	Terawatt hour (=10^9 kWh)
VLLW	Very low-level radioactive waste

Annex 1

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Mr. Ron HUTCHINGS	Radiation Protection and Waste Management Division (at the First Meeting)

Annex 2

COUNTRY REPORTS ON LOW-LEVEL WASTE REPOSITORY COSTS

AUSTRALIA

General

Australia does not have a nuclear power industry; however, it has currently accumulated some 3 500 m^3 of radioactive waste arising from over 40 years of research, medical and industrial use of radionuclides. This figure does not include wastes from mining of radioactive ores which are generally disposed of at the mine site in accordance with national standards and State/Territory regulations.

Australia's Commonwealth, State and Territory Governments are responsible for the management of the radioactive waste produced within their jurisdictions. Radioactive waste is presently held at some fifty interim storage sites throughout Australia. The waste is accumulating slowly, at a rate of less than 60 m^3 per year. Western Australia has already established a final repository for its low-level radioactive waste.

The National Health and Medical Research Council's (NHMRC) Code of Practice for the Near-Surface Disposal of Radioactive Waste in Australia (NHMRC 1992) provides guidelines for the safe siting, design and operation of a near-surface disposal facility. The purpose of this Code is to "provide a basis for the near-surface disposal of radioactive waste in a way which ensures that there is no unacceptable risk or detriment to humans, other biota or the environment, at present, and that future risks or detriment will not exceed those currently accepted". The Code is based on International Atomic Energy Agency (IAEA) standards.

The NHMRC *Code* defines four categories of radioactive waste for disposal and management purposes. Wastes suitable for near-surface disposal are separated into categories A, B and C. The Code provides generic activity concentration limits for each category of waste. A fourth category, S, describes wastes that are not suitable for shallow ground burial.

Some types of radioactive waste contain very low levels of radioactivity, or radionuclides of short half life and in small quantities. They are considered safe to dispose of in conventional ways, such as designated municipal tips or sewerage systems (for very low-level liquid wastes). The NHMRC has developed a *Code of Practice for the Disposal of Radioactive Wastes by the User* (1985), which sets out guidelines and safe practices for the disposal of these very low-level wastes. State/Territory regulations usually contain additional requirements to the *Code,* with which users are required to comply.

In 1992, the Commonwealth started a study to identify a site in Australia for a national near-surface disposal facility for Australia's low-level and short-lived intermediate level radioactive waste. The design concept proposed is an engineered trench structure. The suggested approach is to select a site and design for the repository which uses the natural characteristics of the site to control radionuclide migration from the disposal site.

The study has involved development of site selection criteria using IAEA guidelines which take account of factors such as remoteness from population centres, arid climate and proximity to transport routes. Geographic information systems have been used to apply site selection criteria to identify potential regions.

A public discussion paper on the first phase of the study explaining the proposed site selection process and methodology was widely circulated for comment by the public and interest groups. A follow-up report responding to the public comments received was also published.

Phase 2 involved reapplication of the methodology, adjusted to take account of public comments to identify eight broad regions in Australia likely to contain suitable sites for a national repository.

The results of Phase 2 were released as a public discussion paper in July 1994 and a report responding to public comments on this discussion paper was released in November 1995.

Phase 3 of the Study was suspended pending Government consideration of the report of a Senate Select Committee inquiry into radioactive waste management in Australia.

The Committee reported in April 1996 and the Government responded to the Committee's recommendations in November 1996. In its response to the report, the Government announced its intention to resume the national repository site selection study. The next stage (Phase 3) of the site selection study will involve selection of one of the eight regions identified during Phase 2 for detailed field investigation to locate a suitable site.

Nuclear Power Generation

Australia does not have a nuclear power industry.

Information on the repository

Proposed national near-surface repository for low-level and short-lived intermediate-level radioactive waste

Name and location

National Radioactive Waste Repository. A site for the proposed national repository has not yet been chosen.

Status

The national radioactive waste repository site selection study is still in progress, and a site for the national repository has not yet been chosen. The next phase of the study will involve the Commonwealth selecting one of the eight broad regions identified during Phase 2, for more detailed field investigation, to locate a suitable site.

The Commonwealth States and Territories are each responsible for the management of radioactive waste produced within their jurisdictions. Some States have central interim stores while in others radioactive waste is stored by the user. Within the Commonwealth, interim storage of radioactive waste is the responsibility of the agency which generates it.

Time schedule

The time schedule for siting the proposed national repository is currently under revision. Operational details have yet to be decided. It is expected that the repository will operate for 50 years and have an institutional control period of 100-300 years.

Operator

The operator for a national radioactive waste repository will be decided once a preferred site is selected.

Type

The proposed national repository is expected to be a near-surface disposal type facility.

Geological formation

A site has not yet been chosen.

Types, origins and amounts of radioactive waste

Types: low-level radioactive waste and short-lived intermediate-level radioactive waste.

Origins: waste from research, medical and industrial uses of radionuclides which has accumulated over the past forty five years. The repository will also be used to dispose of future waste arisings.

Amount: less than 3 500 m^3. Future waste arisings are expected to accumulate at a rate of less than 60 m^3 per year.

Reception capacity

The frequency of disposal campaigns has not been decided and will depend on the site selected, the repository design and waste arisings. Based on the existing inventory and estimated annual arisings, the facility will need to provide disposal capacity for around 7 000 m^3 of low-level and short-lived intermediate level waste. The final reception capacity will be influenced by repository design, conditioning and packaging requirements, the institutional control period decided and future waste arisings.

Safety requirements

The design of the proposed national repository has not yet been finalised. However, the repository site and its design, which would involve multiple engineered and natural barriers, is expected to provide for adequate containment of radionuclides within the repository during its operational period and well into the future, in accordance with international standards.

Other features

The repository disposal area will occupy a space of 100 x 100 m. The repository will take up a total area of 225 hectares including a large buffer zone.

Costs

Costs for the proposed national repository are as yet unknown, and will largely depend on the site selected and repository design.

Possible ways of reducing costs

The repository will be operated on a cost-recovery basis to encourage waste minimisation practices amongst waste producers.

Western Australia's intractable waste disposal facility (IWDF)

Name and location

Mount Walton East Intractable Waste Disposal Facility (IWDF), located on 25 km^2 of Crown Reserve Land, 475 km north-east of Perth, in the State of Western Australia.

Time schedule

The site received its first low-level radioactive waste (LLW) in 1992, and received two other consignments of LLW in 1994.

Operator

The Waste Management Division of the Western Australian Department of Environmental Protection is responsible for the operation of Western Australia's IWDF.

The IWDF is regulated by the Environmental Protection Authority under the 1986 Environmental Protection Act, through ministerial conditions imposed on the site. It is also regulated by the Radiological Council under the Radiation Safety Act.

Type

The IWDF site at Mount Walton East is a near-surface burial facility for low-level radioactive waste (as defined in the NHMRC Code of Practice for Near-Surface Disposal of Radioactive Waste in Australia 1992).

Types, origins and amounts of radioactive waste

The repository can accept only LLW (plus a variety of non-radioactive intractable materials for trench or shaft burial at the IWDF, sited at least 500 m from any radioactive waste below ground, trench or shaft).

A variety of non radioactive waste may also be disposed of by trench or shaft burial at the facility. Only waste generated in Western Australia may be disposed of at the IWDF. Waste materials of higher radioactivity than LLW as defined in the NHMRC Code must not be disposed of at the IWDF. Any such materials are generally held in registered and controlled secure above ground storage.

Western Australia has no nuclear power industry or research reactor. The repository has accepted LLW from: medical, educational and research applications; by-products of processing of mineral sands (equipment contaminated with radium scale); mining ore samples; industrial isotope uses; and items withdrawn from service such as smoke detectors and luminescent "EXIT" signs.

The total volume of LLW (including overdrums, cement fill in containers and packaging containers) buried at the IWDF since 1992 is:

Shaft 1	66 x 200-litre drums	13.2 m^3
Shaft 2	69 x 200-litre drums	13.8 m^3
Trench 1	3 x 6 metre-long seatainers	96.7 m^3
TOTAL		**123.7 m^3**

Reception capacity

The reception capacity cannot be stated in ordinary terms. It was considered in an August 1992 report by Industrial Risk Management entitled "Risk Assessment for Radioactive Waste Disposal at Mount Walton", which stated on page 3 that:

"It is concluded that there is effectively no basis on which to establish that there should be a maximum total site activity limit. In effect, there is no theoretical limit to the total activity which may be stored at the proposed waste disposal site."

The site is not operated in a daily/weekly or monthly manner. Waste disposal campaigns are initiated once sufficient waste has been accumulated.

Based on the existing inventory of waste and currently known future arisings, the total amount of buried LLW at the repository after 20 years is expected to be around 120 000 m^3, but will depend on Western Australia's waste arisings.

Safety requirements

The characteristics of the site, (stable geology, located at top of surface water divide, underground burial, etc.) require no specific measures to be implemented. Radiation compounds are fenced off and locked, and regular site inspections carried out.

Costs

Due to the complicated historical development of the IWDF from 1986 to 1992 – with many studies by government, consultant scientists and engineers, related to site screening and changing purposes of the site (from disposal of rare earth plant LLW waste, plus an integrated high temperature incinerator and PCB storage/disposal facility) – specific planning and R&D costs are very difficult to identify.

Possible ways of reducing costs

Lower standard of packaging or on-site containment, but these are not envisaged.

COSTS OF WESTERN AUSTRALIA'S INTRACTABLE WASTE DISPOSAL FACILITY

(million Australian Dollars, AUD)

Planning and licensing		Construction[1]		Operating (per year)[2]			
				Years without LLW disposal		Years with LLW disposal	
Planning[3]	1	Shafts 1 and 2	0.18				
Licensing[4]	0.02/year	Trench 1	0.06	Administration and site management	0.044	Administration and site management	0.0860
		Surface facilities	0.56			Handling/packaging and overpacking	0.0330
				Radioactivity monitoring	0.003	Radioactivity monitoring	0.0030
				Access road maintenance	0.030	Access road maintenance	0.0300
Total		**Total**	**0.80**	**Total**	**0.080**	**Total**	**0.1524**

Operating costs during institutional control of the repository (per year)	
Radioactivity monitoring	0.003
Administration and site management	0.04
Access road maintenance	0.03
Total	**0.08**

Exchange rate as of 1 July 1995

1.41 AUD = 1 US$

Volume of LLW buried since 1992	125 m^3

Notes:

1. To date, two shafts and one trench have been constructed where a total of 125 m^3 of waste have been buried.
2. Operating costs are estimated figures due to the campaign nature of disposals to date.
3. Planning costs do not correspond to specific costs, but are an estimated figure to cover government and private costs associated with the preparation and assessment of the proposals, and reporting them as well as participation in community consultation.
4. Costs of meeting registration, Ministerial Conditions and Commitment's requirement.

BELGIUM

General

ONDRAF/NIRAS, the Belgium Agency for Radioactive Waste Management is entrusted with all aspects related to waste management in Belgium, including final disposal. The reference scenario foresees a surface disposal route for low-level radioactive waste (LLW) and very low-level radioactive waste (VLLW) after a period of interim storage. The design and data of the planned surface repository presented below are valid as of 1 July 1995, and do not take into account a possible modification of the design prior to the date of the publication of this report.

The repository is scheduled to be operational by 2004. Design capacity is 60 000 m^3 (100 000 m^3 of conditioned low-level short-lived wastes). The site surface is about 30 hectares. The design is based on the concept of multiple protective barriers. The engineered barriers are designed to minimise both the rainwater inflows and the leaks of radionuclide contaminated water from the inside. In addition, the geology must be able to trap escaping nuclides, or to channel them into well-defined zones.

The engineered barriers consist of disposal modules protecting the waste from water infiltration and other intrusions, and a multilayered shielding protecting the modules against outside hazards, especially climatic ones.

The disposal modules of 2 000 m^3 capacity are quite similar but more sophisticated than the surface interim storage buildings used, prior to disposal. They are made of two 1 000 m^3 capacity cells, rectangularly shaped concrete boxes, completely watertight thanks to their wall thickness (about 1 m), exceeding the usual design standards. The rectangular-shaped cross-section of a 7.7 m high cell is 15 m x 17.3 m, resulting in a net capacity of nearly 2 500 normalised packages (400 litres), stored in six or seven layers with an occupation rate of about 50 per cent.

This volume provides adequate seismic behaviour of the structure, low crack frequency and therefore high watertightness. The capacity of one cell is compatible with the disposal rate of about 1 000 m^3/year, and offers a good gross/net volume ratio.

The modules are assembled on the site in a specially built hangar, and disposed in rows of 10 modules, called tumuli. A tumulus has a capacity of 20 000 m^3.

The tumuli are protected by a multilayered shielding with drains on the side and sand on the top. It hinders penetration of rainwater and protects the waste from outside climatic or biological hazards. The device consists of multiple protective layers, some natural, some artificial. In the preliminary design, the multilayered system is about 5.5 m thick (see Figure A2.1) .

The “life” of the surface repository involves five sequential phases:

(i) Preparation over 5 years includes all front-end steps necessary before start-up of site operation: site characterisation; final site selection; detailed safety report and impact assessment; purchase of land; preparation of the disposal surface; communication policy; building of road infrastructure outside the site for local residents; building of a visitor centre, and of a prototype tumulus on the site; engineering studies; and project management.

(ii) Disposal operation: during this phase, scheduled to last about 55 years, the waste is brought to the disposal facility. This includes constructing, filling up, backfilling and closing the disposal module with a concrete plate, as well as installing the protective shielding on the tumuli.

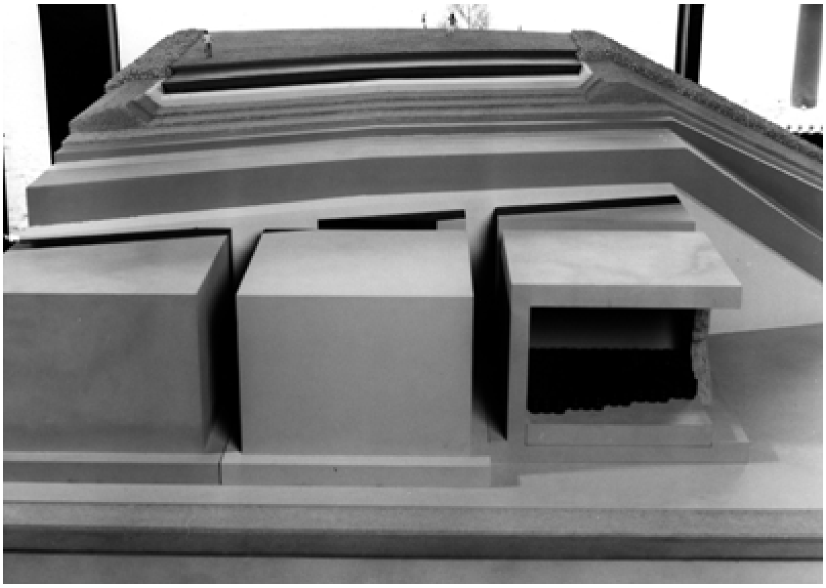
(iii) Sealing of the site: this period lasts about 12 years after the last disposal operations. The last protective shieldings are brought into place, and the site and its organisation are progressively decommissioned.

(iv) Institutional monitoring: once the storage capacity has been filled and sealed, some monitoring of the site is maintained in order to prevent disturbances from the outside. This phase of low activity (mothballing) includes the maintenance of the fence, of green spots in and around the site, and water monitoring downstream, for at least 200 years.

(v) Back to green field: it starts when the site has been freed from all remaining radiological constraints and is available again for unrestricted human use.

The site can accommodate both LLW and VLLW. No difference is made between those two waste forms. The acceptability of waste for the surface disposal depends on the presence of long-lived radionuclides. Exemption levels are the same as those used by international organisations, the European Union and the IAEA.

Figure A2.1 **An artistic view of LLW repository**



Nuclear power generation

Data as of 1 July 1995 are as follows:

Total net nuclear capacity	5.6 GWe
Number of nuclear units	7
Nuclear electricity generated in 1995	39 TWh
Cumulated nuclear electricity generation (1975-1995)	594.9 TWh

Information on the repository

Name and location

No site has yet been selected.

Status

The LLW repository has not yet been operated as the site remains to be specified.

Interim storage is operated in Mol-Dessel before disposal, scheduled around 2004.

Time schedule

The time schedule of the repository is as follows:

Beginning of construction	1999-2001
Completion of construction	2004
Opening of site	2004
Date of closure	2070 approximately
Period of institutional control	200-300 years after closure

Operator

The repository will be operated by ONDRAF/NIRAS, owned by the Belgian state.

Type

The repository is a surface type one (See Figure A2.1). In 1995, retrievability was not required. Radioactive waste (in 400-litre drums) is stacked into 6 or 7 layers. A multi-layer shielding about 5.5 m thick will be used.

Geological formation

Unknown as the site has not yet been specified.

Types, origins and amounts of radioactive waste

Types: LLW and VLLW will be accepted in the repository and will be treated without distinction. The radiation limit of the waste has not been fully settled as yet and the form of packaging will be in 400-litre drums.

The inventory of LLW to be disposed of at the repository after 2004 includes:

- operational waste production (in conditioned form) in NPPs, which is about 10 m^3/TWh (in 400-litre drums). This figure does not include waste originating from fuel cycle facilities;
- decommissioning waste from nuclear installations;
- waste from fuel manufacturing;
- waste from research facilities;
- waste from radioisotope users; and
- historical waste.

LLW waste from the electricity sector including decommissioning of nuclear power plants represents about 85 per cent of the total waste.

Reception capacity

Reception capacity of the repository after 2004 will be 1 000 m^3 per year and the final base case reception capacity is assumed to be about 60 000 m^3. Daily reception capacity will be about 10 drums (4 m^3) in the main operational period.

Safety requirements

Anticipated events for safety evaluation are intrusion, earthquake, waterflood and airplane crash. Site selection criteria have been defined taking into account earthquake and waterflood; intrusion scenarios are considered in the safety analysis; airplane crash is considered in the repository design.

Regarding radiation protection and safety standards, all regulatory aspects have not yet been settled by the regulatory authorities.

Other assumed features

The surface of the repository will be 0.30 km^2; the number of tumuli will be 3 in 2070; and the number of cells will be 60 in 2070. Rain water management is described above.

Costs

All costs are given in real terms, i.e. undiscounted costs expressed in national currency unit (Belgian francs, BEF), as of 1 July 1995, and past costs are inflated using national inflation indicators unless otherwise stated. Contingency factors are not included.

COSTS

(million Belgian Francs, BEF)

Planning and licensing		**Construction**		**Operating** (per year)[1]		**Closure**	**Miscellaneous**	
R&D	400	Design	350	Administration	40	2 400	Communication	600
Site screening	150	Tumuli	2 215	Handling			Public relations	200
Sub-total	**550**	Facilities	1 200	Overpacking			Economic incentives	To be decided
Licensing	150			Filling	11			
				Backfilling				
				Others				
				Radioactivity monitoring	~10			
				Number of staff	55			
Total	**700**	**Total**	**3 765**	**Total**	**146**	**Total 2 400**[2]	**Total**	**800**

Operating costs during institutional control of the repository
Not known

Exchange rate as of 1 July 1995
28.47 BEF = 1 US$

Capacity of the repository	60 000 m^3
Annual rate of waste delivery	1 000 m^3

Notes:

1. Total operating cost is estimated to be 9 800 million Belgian francs during 67 years of operation, and the average operating cost is then calculated to be 146 million Belgian francs per year.
2. Very preliminary estimate in 1995.

CANADA

General

Policy

Natural Resources Canada (NRCan) is the department of the Federal government responsible for energy policy including nuclear energy, and extending to radioactive waste management. In 1995, NRCan initiated a consultation process with major stakeholders, to develop a radioactive waste policy framework. This process resulted in the announcement by the government, in 1996, of a policy framework for radioactive waste that will guide Canada's approach to the disposal of nuclear fuel waste, low-level radioactive waste and uranium mine and mill tailings into the next century. The framework lays out the ground rules and sets the stage for the further development of institutional and financial arrangements to implement disposal in a safe, environmentally sound, comprehensive, cost-effective and integrated manner.

Regulation

Radioactive waste management is regulated by the Atomic Energy Control Board (AECB), the nuclear regulatory agency in Canada. The objectives of radioactive waste disposal, as stated in the AECB regulatory guideline (R-104), are to minimise any burden placed on future generations and to protect the environment and human health, taking into account social and economic factors.

A general requirement of disposal in R-104 is that the predicted radiological risk to individuals from a waste disposal facility shall not exceed 10^{-6} fatal cancers and serious genetic effects per year, calculated without taking advantage of long-term institutional controls as a safety feature. It is recognised that for some waste types, such as the large-volume waste at some uranium mining and milling sites, there may be a need for continued institutional controls. In such cases, an optimisation study is to be performed to determine the preferred option.

Legislation to replace the Atomic Energy Control Act of 1946 with a new Act has been approved by parliament and is expected to be effective in 1997. Under the new Act, called the "Nuclear Safety and Control Act" (NSCA), the AECB will be renamed the "Canadian Nuclear Safety Commission", and will have a clear mandate to establish and enforce national standards with respect to the health, safety and environmental aspects of nuclear activities. These will include the authority to require financial guarantees from waste producers, and to order remedial actions in hazardous situations, with responsible parties to bear the costs of such actions.

Low-level radioactive waste

In Canada, low-level radioactive waste is defined as all radioactive waste except high-level and uranium mine and mill tailings. For administrative purposes, low-level radioactive waste is divided into two broad classes or categories: waste from ongoing activities, and waste from historical activities.

Relatively little waste was produced from ongoing activities in 1995, i.e. approximately 5 000 m^3, including about 300 m^3 from decommissioning activities. The total volume at the end of 1995 was 180 000 m^3. Waste from ongoing activities includes non-fuel waste currently being produced from Canada's nuclear reactors, nuclear fuel processing and fabrication facilities and from medical, research and industrial uses of radioisotopes. The waste also includes processing residues from industrial operations and contaminated used equipment, materials, rags and protective clothing. Decommissioning waste arises when nuclear facilities are dismantled at the end of their operational life. Major producers operate their own interim storage facilities, pending the development of permanent disposal facilities. Atomic Energy of Canada Limited (AECL) provides a low-level radioactive waste (LLRW) management service on a user-pay basis for producers of small volumes of low-level waste.

Historic low-level radioactive waste, generally consisting of process residues and contaminated materials mixed with soils, was generated by producers or owners that no longer exist, or cannot be held responsible for the waste. These wastes are the responsibility of the Federal government, either through the Low-Level Radioactive Waste Management Office (LLRWMO), the federal agent established for the clean-up of historic sites and management of the resulting waste or, in some cases, through arrangements with the current owners of sites. These wastes total more than one million m^3 and represent almost 90 per cent in volume of the total low-level radioactive waste current inventory. Most of the historic waste is located at sites in the Port Hope area of Ontario with smaller volumes at various sites across Canada. Clean-ups have been performed at many sites, with waste consolidated at interim storage sites.

Nuclear power generation

Data as of July 1995 are as follows:

Total net nuclear capacity	15.4 GWe
Number of nuclear units	22
Total nuclear electricity generated in 1995	94.0 TWh
Cumulated nuclear electricity generation until 1995	1 056.9 TWh

Information on the repository

There are currently no facilities licensed in Canada as low-level waste disposal facilities. Owners and producers of waste are responsible for the management and disposal of their waste. One or more disposal facilities are required for low-level radioactive waste, and major waste producers and owners are working towards this objective. Ontario Hydro, the largest nuclear power utility, has outlined options either to develop its own facility, which could be co-located with the nuclear fuel waste disposal facility, or to work in co-operation with other waste producers to develop a multi-user disposal facility. Significant progress has been made in recent years in two areas:

1) At Atomic Energy of Canada Limited (AECL): one step in the transition from storage to permanent disposal of low-level waste is the construction of a prototype disposal vault termed IRUS (Intrusion Resistant Underground Structure). IRUS has been designed as a modular concept where each unit is a near-surface concrete vault with a 2 000 m^3 capacity, for low-level and short-lived intermediate-level waste with a hazardous lifetime of up to 500 years. An application for a construction licence of a demonstration unit has been made to the AECB. Construction of this facility, at the Chalk River Laboratories property of AECL, could begin in 1998.

2) A voluntary siting process, to locate a site for a permanent disposal facility for historic waste, now located primarily in the Port Hope area, was initiated by the Federal government in the late 1980s. The cornerstone of the process, implemented by an independent Siting Task Force established by the Minister of Natural Resources Canada, is voluntary participation by potentially interested communities. This resulted in the community of Deep River (Ontario) volunteering, in 1995, as a host community on the basis of an agreement-in-principle (CAP) negotiated with the Siting Task Force and supported by a community referendum. The proposed site is at the Chalk River Laboratories, property of AECL, which is within the Municipality of Deep River.

In July 1996, the Minister of Natural Resources Canada announced the federal government's intention to proceed with negotiations to develop a legal agreement establishing the terms and conditions, based on the CAP, under which the town of Deep River would agree to host the facility. Negotiations based on the CAP ended on 31 December 1996. Further negotiations, to be based on a different set of terms and conditions, were under discussion between the government and the town at the time this report was being prepared.

CZECH REPUBLIC

General

In the Czech Republic, practically two separate and mutually independent systems of handling radioactive waste exist. The responsibility for the handling of waste generated outside the nuclear fuel cycle (institutional waste) rests on the joint stock company, ARAO (Agency for Radioactive Waste). The responsibility for waste produced by the nuclear power facilities is borne by the operator of the nuclear power plants, i.e. CEZ, a.s.

When the new Nuclear Law comes into force, the responsibilities for disposal of all radioactive waste will have been passed on to the State and waste disposal will have been secured by the respective national agencies.

ARAO

ARAO, the Agency for Radioactive Waste, is entrusted with the collection, treatment, transport and disposal of radioactive waste outside the nuclear fuel cycle. The present disposal route is the one for disused underground mines.

The two repositories which are now in operation for these purposes are scheduled to be operational to the year 2035, approximately. Richard repository has a design capacity of around 10 500 m^3 and Bratrství repository has a capacity of around 290 m^3 for conditioned waste. The design of the repositories is based on the concept of multiple protective barriers. The engineered barriers are designed to minimise rainwater flow and leaks of radionuclide contaminated water from inside. The geological environment is able to trap escaping radionuclides or to channel them into well-defined zones.

Exemption levels will be specified in the new “Decree on the assurance of radiation protection by activities leading to irradiation”. All radiation protection and safety standards are now reviewed by the State Office for Nuclear Safety, in compliance with the new atomic law which came into effect on 1 July 1997.

The sources of wastes are: research; radionuclide uses; and historical wastes from decommissioning of radionuclide laboratories.

Disposal facility for artificial radionuclides: Richard Litomerice

Richard disposal facility near Litomerice has been in operation since 1964. It was built as a relatively large-capacity repository, for low and intermediate level radioactive waste and spent sealed sources, in the area of the abandoned limestone mine, Richard II. During World War II, an underground factory, working for military purposes, was situated in this mine. The cost for the adaptation amounted to more than 10 million Czech Crowns. However, only a part of Richard II mine was used as a disposal facility.

Until the end of 1996, the total volume of the disposed radioactive waste amounted to about 2 000 m^3.

The underground water level is approximately 50 m below the disposal modules, in a sandstone layer, and the repository is continuously monitored for possible contamination of water, land and air.

Richard II repository accepts only waste with artificial radionuclides. Its total volume is 16 684 m^3, with 8 612 m^3 available for disposal and 8 072 m^3 used for communications, gangways and corridors. By 1996, about 5 200 m^3 were filled with waste, so that about 2 800 m^3 still remain free for disposal. As the filling factor is about 40 per cent, about 1 120 m^3 are still available for emplacement of packed waste.

Tritium is one of the most important radionuclides from the viewpoint of radiation protection, especially because of its high content in the waste, volatility and difficulty of immobilisation. Other critical radionuclides are ^{241}Am, ^{239}Pu, ^{137}Cs, ^{14}C and ^{90}Sr.

A project has been worked out for the construction of additional capacity of 2 800 m^3 and its realisation is under way.

Following recent hydrological studies, it appears that the isolation characteristics of this site are rather good. The underlying geological bed of the site is formed partly by marl. Small amounts (several litres per day) of mine water flow out during the entire year. The system for hydrological and radiological monitoring is continuously developing and improving. The packages are in good condition. A central isolated retention basin for the accumulation of mine water has been built. Recent studies revealed that there is no threat to the surrounding environment. However, the following measures need be taken in order to guarantee full safety:

- continuous revision of the static conditions in the repository, making all necessary adaptations;
- continuous revision and repair of the drainage system;
- running a systematic monitoring of the mine water and air in the disposal facility and outside;
- running a deep monitoring system in agreement with the hydrological studies carried out so far; and
- furnishing the disposal facility with additional features for the safe handling of waste.

Some of these measures are currently being developed and others have partly been realised.

Safety studies are still under way and their results are being used to enhance safety and radiation protection at this site.

Disposal facility for natural radionuclides: Bratrství Jáchymov

The Bratrství Jáchymov disposal facility was built in the gallery of an abandoned uranium mine with five chambers for disposal. It is used for waste containing natural radionuclides, predominantly ^{226}Ra, ^{210}Po, ^{210}Pb, uranium and thorium nuclides. The waste also includes spent sealed sources and neutron sources, mostly containing ^{226}Ra and ^{210}Po. The main reason for the separation of these waste types from the others is the radon emanation that would cause serious problems in the Richard disposal facility.

The cost for the basic adaptation of the former uranium mine amounted to about 1.2 million Czech Crowns. The disposal facility has been in operation since 1974.

The volume of disposed wastes is about 250 m^3 and the free capacity is about 40 m^3. It is supposed that the disposal facility will be in operation until approximately 2035. The disposed activities are about 10^{12} Bq of ^{226} Ra, 10^9 Bq of ^{232} Th and 10^9 Bq of other radionuclides.

The possibility for expansion of this disposal facility has been rejected by the local authorities for the time being.

The safety analysis shows that this mine cannot be considered to be a completely stable system with a time horizon of at least 10^4 years, the period necessary for a substantial decrease of the ^{226}Ra activity with a half-life of 1 600 years. The acceptance of the disposal facility is based on the fact that only a small part of the activity that was originally mined from this locality has been returned to the repository.

To increase the safety assurance of the disposal facility, the following provisions are being made:

- a tracer examination of the underground water movement using artificial radionuclides;
- hydrochemical determination of the mine waters, mineral waters and surface waters;
- estimation of the engineering and geological stability of the disposal site; and
- continuous geotechnical works and maintenance with the aim of improving the geotechnical stability of the galleries and the drainage system.

CEZ, a.s.

The waste produced during the operation of the nuclear power plants is being disposed of in the shallow land repository at Dukovany, situated in the area of the power plant. This repository is intended for the needs of Dukovany and the future Temelín nuclear power plants.

Disposal facility for waste from power generation of Dukovany

The repository consists of 112 pits, each 17.3 m long, 5.3 m wide and 5.4 m deep. The pits are arranged in two double rows. The geometrical volume of the repository is 55 450 m^3, thus providing a capacity for disposal of 30 000 to 35 000 drums filled with conditioned waste. The packaging unit is a 200-litre drum, while the overpacks are being used for disposal of the compacted solid wastes. The handling and disposal operations are being carried out by a full-portal gantry crane. The service building equipped with the crane remote control room, the dressing rooms and the sanitation installations is located within the fenced area of the repository (see Figure A2.2).

Figure A2.2 **Dukovany LLW and ILW Repository**

The safety of the repository is ensured primarily by the quality of the geological basement and by a system of multiple engineered barriers against dispersion of radioactive substances. The barriers are formed by: the sealing of the repository; the structure of the pits, and the matrix used in the liquid waste solidification process.

The planning and operation of the repository can be divided into several phases:

a) Search and investigation of siting followed by construction of the repository. This phase lasted from the early 1980s until 1994.

b) The operation of the repository was initiated in 1994 and four pits were filled up by the end of 1996. The initial phase of operation will last up to the end of 1999, when the operation of the repository is to be evaluated and the necessary safety analyses are to be completed, based on the actual values of the deposited waste. On the basis of this evaluation, a decision will be made on the filling up of free space in the individual pits with concrete. In accordance with the current estimates, the operational phase will last up to the year 2040. This date is based on the expected decommissioning schedule of Temelín.

c) In the second phase, an extension of the repository is planned so as to enable the disposal of decommissioning waste. The period of construction and subsequent operation is expected to last from 2040 to around 2100.

d) Closure of the repository is at present elaborated at conceptual level. The safety analyses will be worked out after closing the repository. Within the scope of these studies, the conditions necessary for the implementation of the institutional control, its duration and limitations, if any, in utilising the site will be specified.

The limits and conditions applied to the repository allow the disposal of service effluents which can be classified as LLW and ILW waste. For the waste that cannot meet the specified limits, reprocessing or disposal in other repositories can be envisaged provided that the limits applicable to those repositories are met.

Nuclear power generation

Status by the end of 1996:

Total net nuclear capacity (Dukovany)	1.75 GWe
Number of nuclear units	4
Total nuclear electricity generated in 1996	12.849 TWh
Cumulated nuclear electricity generation (1985-1996)	134.516 TWh
Total output of units in process of construction (Temelín)	1.824 GWe

Information on the repositories

Name and location

a) Richard near Litomerice;
b) Bratrství near Jáchymov;
c) Dukovany nuclear power plant at Dukovany.

Status

a) Richard: in operation;
b) Bratrství: in operation;
c) Dukovany: the repository has been in operation since 1994; the first operational phase in connection with the operation of nuclear power plants will last until 2040.

Time schedule

	Richard	**Bratrství**	**Dukovany**
Beginning of construction	1962	1972	1987
Completion of construction	1964	1973	1994
Opening of site	1964	1974	September 1994
First disposal	1964	1974	
Closure	~2035	2035	2040
Institutional control	200 to 300 years after the closure	200 to 300 years after the closure	*

* The duration of the institutional control will depend on the decision of the State Office for Nuclear Safety; it is expected to be 300 years after the closure of the repository.

Operator

Richard and Bratrství

Both repositories are operated by ARAO.

Dukovany

The repository is owned and operated by CEZ, a.s. The power generation company CEZ, a.s., is a joint-stock company, of which 67.46 per cent is owned by the State (the National Property Fund of the Czech Republic), 1.1 per cent by the Restitution Investment Fund, 26.92 per cent by legal entities, and 4.52 per cent by individuals.

Type

Richard and Bratrství

Both repositories are underground disused mines. Retrievability is not required. Radioactive waste (in 200-litre drums) is stacked into 4 to 7 layers. Multilayer lead, depleted uranium, concrete or baryte-concrete shielding is used, depending on the activity contained in the waste.

Dukovany

The repository is an above ground vault. Retrievability is not required. Radioactive waste placed in 200-litre drums is stacked into 6 layers. The free space among the drums is planned to be filled up with concrete.

Geological formation

Richard

The repository is in a clay-limestone of light grey colour with organodetrical structure. The content of calcite is 80-90 per cent. The ground layer of the disposal site is about 50 m deep, in a grey marl limestone. Under this very impermeable layer lies a chalk aquifer formed in medium grain weakly clay sandstone.

Bratrství

The repository is in a mica-silicate schist.

Dukovany

The area in which the repository is situated is formed by quaternary sediments overlying a basement composed of gneiss and migmatites. The repository is located at the local watershed of the Jihlava and Rokytná rivers. The distance between the two streams is 1.7 km.

Types, origins and amounts of radioactive waste

LLW and ILW are accepted in Richard and Bratrství repositories. Radiation dose equivalent is limited to 1.0 mSv/h at a distance of 5 cm from the surface of the drum.

The form of packaging is normally 100-litre drums inside 200-litre drums and the layer in between is filled with concrete; the State Office for Nuclear Safety can approve exemptions in justified cases.

Dukovany can accept LLW and ILW resulting from operation of nuclear power plants, packaged in 200-litre drums, and also HIC type packages which will be used in the future.

Inventory of waste disposed (as of 1 July 1995)

Origin	Richard		Bratrství		Dukovany
	Amount		Amount		Amount
	m^3	t	m^3	t	m^3
Electricity sector	–	–	–	–	30 000-35 000*
Research facilities	1 541.6	2 080	8.0	12.32	–
Radioisotopes	385.4	520	154.4	233.3	–
• production	289.0	390	24.4	36.8	
• medical uses	57.8	78	130.0	196.5	
• other uses	38.2	52	–	–	
TOTAL	1 927.0	2 600	162.4	245.62	30 000-35 000

* Not including decommissioning waste.

Reception capacity

Capacity of the repositories

	Richard	Bratrství	Dukovany*
Capacity of the repository (m^3)	10 500 (LLW 9 450 + ILW 1 050)	290 (LLW 260 + ILW 30)	18 520
Annual rate of waste delivery (m^3)	78	10	310

* The reception capacity of Dukovany after 2002 will be 430 m^3 per year, the final capacity being no less than 30 000 m^3 of conditioned waste. The daily waste reception capacity within the period of service is 80 drums.

Safety requirements

Richard, Bratrství

- anticipated events for safety evaluation are intrusion, earthquake, waterflood and airplane crash. These scenarios were considered in the safety analysis;
- individual dose equivalent limit is 2.5 x 10^{-4} Sv per year.

Dukovany

- anticipated events for safety evaluation are intrusion, waterflood, fire and handling accidents;
- any disposal of waste of such activities and in such amounts that might result in exceeding the rated individual dose equivalent (IDE) values for individuals of population of a value of 10 μSv/year, and committed dose equivalent (CDE) for population of a value of 1 manSv/year due to the repository operations is excluded. The dose rate on the waste package surface is limited to 0.9 Gy/h.

Other features

The number of chambers is 16 at Richard and 5 at Bratrství. Hydrological conditions are described above.

The area of Dukovany repository is 0.0131 km^2 (total area of 4 trenches). The number of trenches is 4 (2 x 2 at present), and will be 6 in 2040. The number of pits is 112 at present and will be 168 in 2040.

Rainwater is being collected in the rainwater sewerage system common to the entire premises of the nuclear power plant.

Costs

National Currency Unit is Czech Crown (CZK). All the costs are given in real terms, i.e. undiscounted costs expressed in national currency unit as of 1 July 1995. Past costs are inflated using national inflation indicators.

Possible ways of reducing costs

Investment costs arose only during construction. So far, there have been no other investment costs during further operation. Operation costs are minimised mostly by reducing waste volumes during the use of radionuclides. The procedure for the closure of the repositories has not yet been determined. All operations are optimised with an aim to reducing costs.

COSTS

(million Czech Crowns, CZK)

RICHARD									
Planning and licensing		**Construction**		**Operating** (per year)		**Closure**		**Miscellaneous**	
R&D	6.5	Design	1.7	Administration	1.1		125	Communication or	
Site screening	4.4	Vault	15.5	Handling	4.4			public relations	0.2
Sub-total	**10.9**	Tunnel	4.8	Overpacking	0.7			Economic incentives	1.5
Licensing	0.5	Others	19.0	Others[1]	7.6			Others	0.2
		Facilities	11.2	Radioactivity monitoring	2.1				
				Number of staff	12				
Total	**11.4**	**Total**	**52.2**	**Total**	**15.9**	**Total**	**125**	**Total**	**1.9**

Capacity of the repository	10 500 m^3 (LLW 9 450 + ILW 1 050)
Annual rate of waste delivery	78 m^3

BRATRSTVÍ							
Planning and licensing		**Construction**		**Operating** (per year)		**Miscellaneous**	
R&D	2	Design	0.5	Administration	0.4	Communication or	
Site screening	0.8	Vault	0.1	Handling	0.5	public relations	0.05
Sub-total	**2.8**	Tunnel	1.8	Others[1]	1.8	Economic incentives	0.10
Licensing	0.2	Others	7.0	Radioactivity monitoring	0.5		
		Facilities	4.1	Number of staff	5		
Total	**3**	**Total**	**13.5**	**Total**	**3.2**	**Total**	**0.15**

Capacity of the repository	290 m^3 (LLW 260 + ILW 30)
Annual rate of waste delivery	10 m^3

Exchange rate as of 1 July 1995
26.122 CZK = 1 US$

Note:

1. Maintenance and mine operation.

COSTS *(contd.)*

(million Czech Crowns, CZK)

DUKOVANY[2]								
Planning and licensing		**Construction**[3]		**Operating** (per year)		**Closure**	**Miscellaneous**
Planning	N.A.	Design	2.6	Administration	800		
Licensing	2.5	Trench[4]	107.1	Handling	600		
		Others[5]	7.4	Filling	750		
		Facilities	59.0	Backfilling	unknown		
				Others	3 925		
				Radioactivity monitoring	300		
				Number of staff[6]	5		
Total	**2.5**	**Total**	**176.1**	**Total**	**6 375**	**N.A.**	**N.A.**

Operating costs during institutional control of the repository[7]	
Radioactivity monitoring	0.8
Others	0.1
Total	**0.9**

Exchange rate as of 1 July 1995

26.122 CZK = 1 US$

Capacity of the repository[8]	18 520 m^3
Annual rate of waste delivery	310 m^3

Notes:

2. No clear estimation of all costs classified can be presented according to the individual categories such as projects, site investigation, etc. In the early 1980s, the preparatory work was secured by the national agencies of the previous CSSR, whose budget was by no means connected to the electricity sector. Therefore the quoted costs present only rough estimates.
3. Cost of the future capacity extension was not fully included.
4. 1988 values.
5. Subterranean distributions and networks, dosimetric control, etc.
6. Power plant employees contribute to the operation of the repository.
7. Estimated costs only.
8. The future total capacity can be changed.

N.A. = Not available

FINLAND

General

The waste producer is responsible for the safe management and associated costs of the waste.

The nuclear electricity generating utilities Teollisuuden Voima Oy (TVO) and Imatran Voima Oy (IVO) store and dispose of the operating waste at the power plant sites, TVO in Olkiluoto and IVO in Loviisa.

Nuclear waste management is regulated by the Nuclear Energy Act, in application since 1988. Radiation protection and third party liability are regulated by specific acts. There are safety regulations for handling, storage and disposal of low and intermediate level operating waste.

In 1983, the Council of State made a policy decision on nuclear waste management. The decision stipulates the principles, objectives and time schedules for research, planning and implementation of waste management.

The main regulating authorities are the Ministry of Trade and Industry and the Finnish Centre for Radiation and Nuclear Safety (STUK). STUK regulates the implementation of waste management and issues safety guides. Licenses for the construction and use of nuclear facilities are granted by the Council of State (Government).

At Olkiluoto the repository for operating waste (VLJ) started in 1992. It is designed to take 40 years' worth of arisings, amounting to approximately 8 400 m^3, of which approximately 5 000 m^3 are for LLW.

In Loviisa a repository for operating waste has also been completed and the license was granted in 1998. It is designed to take approximately 5 400 m^3 of operating waste, of which 2 400 m^3 is reserved for LLW.

Both repository designs are cavern type, in crystalline bedrock, and allow for extension of the facilities to take decommissioning waste from the respective power stations.

Nuclear power generation

The following information presents the situation on 1 July 1995:

Total net nuclear capacity	2.3 GWe
Number of nuclear units	4
Nuclear electricity generated in 1995	18.1 TWh
Cumulated net nuclear electricity generation (1977-1995)	283.7 TWh

Information on the repositories

Name and location of repositories

VLJ repository at Olkiluoto is 20 km north of Rauma city, on the west coast.
VLJ repository in Loviisa is 15 km east of Loviisa city, on the south coast.

Status

VLJ repository at Olkiluoto has been in operation since 1992.
VLJ repository in Loviisa is due to start operation in 1998.

Time schedule

Name	Beginning of construction	Completion of construction	First disposal	Closure	Period of institutional control
Olkiluoto	11/1987	05/1991	05/1992	~ 2060	not specified
Loviisa	02/1993	12/1996	1998	~ 2050	not specified

Operator

The repository in Olkiluoto is operated by Teollisuuden Voima Oy, which is owned by the private company Pohjolan Voima Oy (57 per cent), the state-owned company Imatran Voima Oy (27 per cent) and other public owned companies.

The repository in Loviisa is operated by Imatran Voima Oy.

Type

Both repositories are excavated about 100 m down in crystalline bedrock. Retrievability is not required. The waste is mostly packed in 200-litre drums.

In Olkiluoto the drums are placed in concrete boxes (16 drums per box), which are stacked on top of each other in silos.

In Loviisa the drums are put in horizontal rooms.

Geological formation

The rock around Olkiluoto repository is gneissic tonalite. The silos are 70-110 m below ground level and water level.

The repository at Loviisa is 120 m below ground level. It is below water level. The surrounding rock is rapakivi granite.

Types, origins and amounts of radioactive waste

Both repositories can accept VLLW, LLW and ILW.

At Olkiluoto repository LLW is mainly miscellaneous maintenance waste, scrap metal, solidified liquids and filter cartridges. ILL is mainly ion-exchange resins. A total of 1 270 m^3 of LLW and 800 m^3 of ILW was disposed of in Olkiluoto up to 1 July 1995. The total radioactivity was 3.1×10^{13} Bq.

Acceptable total and per volume activities in Olkiluoto VLJ repository

Nuclide	Activity			
	LLW silo		ILW silo	
	Total Bq	Per volume Bq/m^3	Total Bq	Per volume Bq/m^3
^{14}C	1.6×10^8	5×10^6	1.6×10^{11}	1×10^9
^{60}Co	6.9×10^9	5×10^{10}	1.4×10^{12}	1×10^{12}
^{59}Ni	1.6×10^9	5×10^7	3.6×10^{11}	1×10^9
^{63}Ni	2.2×10^{11}	1×10^{10}	5.0×10^{13}	1×10^{11}
^{90}Sr	4.9×10^9	5×10^8	1.6×10^{13}	1×10^{11}
^{99}Tc	8.5×10^6	2×10^5	2.9×10^{10}	1×10^8
^{129}I	5.1×10^4	2×10^3	1.7×10^8	4×10^5
^{135}Cs	5.1×10^5	2×10^4	1.7×10^9	4×10^6
^{137}Cs	5.3×10^{10}	5×10^9	1.7×10^{14}	1×10^{12}
^{238}Pu	1.1×10^6	1×10^5	3.8×10^9	1×10^8
$^{239/240}Pu$	1.7×10^6	3×10^5	5.7×10^9	1×10^8
^{241}Am	1.6×10^6	3×10^5	5.3×10^9	1×10^8
$^{243/244}Cm$	4.9×10^5	1×10^5	1.6×10^9	1×10^8

Reception capacity

The total capacity of Olkiluoto repository is 4 960 m^3 for LLW and 3 400 m^3 for ILW. Total radioactivity in the year 2021 is estimated to be 5.1×10^{14} Bq. Daily reception capacity is 6.4 m^3, i.e. 32 drums in 2 concrete boxes.

The total capacity of Loviisa repository is 2 400 m^3 for LLW and 3 000 m^3 for ILW. It is estimated that total radioactivity will be 10^{14} Bq.

Safety requirements

Anticipated events for safety evaluation are intrusion, earthquake flooding and glacier disturbance.

Dose limit rate for critical person is less than 0.1 mSv per year for normal evolution and less than 5 mSv for accident conditions.

Other features

Total excavation volume including tunnels in Olkiluoto is approximately 90 000 m^3. The repository is normally unmanned. It is operated by the nearby Olkiluoto-1 power station staff.

Total excavation volume including tunnels in Loviisa is approximately 110 000 m^3.

Costs

All costs are given in real terms, i.e. undiscounted costs expressed in national currency units as of 1 July 1995 and past costs are inflated using national inflation indicators. The national currency unit is FIM.

Possible ways of reducing costs

At the Olkiluoto power plant, a new volume reduction method for the compression of LLW drums to half their size has been tested since 1996. This will, of course, increase the effective capacity of the repository and hence reduce the unit cost of waste disposal.

COSTS

(million Finnish Markka, FIM)

OLKILUOTO

Planning and licensing		Construction		**Operating** (per year)		Closure		Miscellaneous	
R&D	40	Design	21	Administration	0.11		25	Real estate tax[2]	0.6 in 1995
Licensing	4	Excavation	60	Handling	0.13				
		Facilities	27	Overpacking	0.49				
				Others[1]	0.78				
				Radioactivity monitoring	0.03				
				Number of staff	2.5				
Total	**44**	**Total**	**108**	**Total**	**1.54**	**Total**	**25**	**Total**	

Operating cost during institution control of the repository
Not available[3]

Exchange rate as of 1 July 1995
4.27 FIM = 1 US$

Capacity of the repository	8 432 m^3 (LLW 4 960 + ILW 3 400)
Annual rate of waste delivery	224 m^3/year

LOVIISA

Planning and licensing		Construction		**Operating** (per year)	Closure	Miscellaneous
R&D	40	Design and				
Licensing	Not available	Excavation	55	Not available	Not available	Not available
		Facilities	20			
Total	**40**	**Total**	**75**	**Total**	**Total**	**Total**

Capacity of the repository	5 400 m^3 (LLW 2 400 + ILW 3 000)
Annual rate of waste delivery	Not available

Notes:

1. Maintenance, insurance, energy, etc.
2. This tax is not included in the calculation of the repository cost.
3. No cost for institutional control is given as it is not yet specified, although some form of institutional control is foreseeable.

FRANCE

General

In France, low and medium-level wastes are managed in compliance with the Fundamental Safety Rules (FSR):

- FSR I.2 deals with the "safety objectives and design bases for long-term near-surface disposal of solid radioactive waste with short or medium half-lives and low or medium level specific activity".
- FSR III.2.e defines the "acceptance conditions for near-surface disposal of packages of solid radioactive waste".

In FSR I.2, performance objectives are set up for near-surface disposal facilities, such as the dose rate limits for the personnel and the general public. According to the safety rule, disposal facilities shall be designed as multibarrier systems confining radioactivity and including the waste packages, the engineered structures and the site geological formation. Site selection criteria defined in the safety rule focus on seismicity, tectonic and geotechnical stability, and hydrogeology.

The repository lifetime spreads over three different periods:

1) the construction and operating period during several decades;
2) the 300-year institutional control period after operation; and
3) the unrestricted access period.

The objective of FSR III.2.e is to specify waste acceptance requirements for near-surface disposal. Two categories of waste are considered: stabilised waste for radioactive materials simply blocked with a binder; and immobilised waste for higher activity materials with a matrix providing confinement.

For waste containing beta-gamma emitters, immobilisation is required if the total activity of these emitters exceeds 37 GBq/tonne (1 Ci/t). Maximum acceptance limits are specified for a number of radionuclides. For example, the acceptance limit for ^{60}Co is 5×10^4 GBq/t and for ^{137}Cs, 3.3×10^2 GBq/t. The maximum acceptance level for waste containing alpha emitting radionuclides is 3.7 GBq/t.

Nuclear power generation

Data regarding nuclear power generation as of 1 July 1995 are as follows:

Total net nuclear capacity	58.5 GWe
Number of nuclear units	56
Nuclear electricity generated in 1995	358.6 TWh
Cumulated nuclear electricity generation until 1975	3 905.1 TWh

Information on the repository

Name and location

Centre de stockage de l'Aube, situated at Soulaines Dhuys (Aube), 250 km east of Paris.

The Centre de l'Aube disposal facility (Figure A2.3) started operation in January 1992, after four years of construction. Its capacity is 1 000 000 m^3 of short-lived low and intermediate level waste.

The design capacity allows reception of 35 000 m^3 per year. However, the present yearly deliveries do not exceed 20 000 m^3 of waste thus allowing an operating period of more than 50 years.

Figure A2.3 **The Centre de l'Aube repository**

Status

The repository started operation in 1992.

Time schedule

Beginning of construction	1987
Completion of construction	1991
Opening of the site	1992
First disposal	1992
Date of closure	2050 (not decided)
End of institutional control	2350 (not decided)

Operator

ANDRA, French National Radwaste Management Agency.

Type

The repository is a surface facility. Retrievability is not required. Radioactive waste is contained either in metallic drums or in concrete boxes. Waste packages are disposed of in concrete structures. A multilayer cap will protect the disposal zone from rainwater after operation.

Geological formation

The geological setting consists of a permeable sandy formation overlying a clay barrier. The site groundwater outlet is well identified. The disposal structures are constructed above ground water level.

Types, origins and amounts of radioactive waste

Types: Low and intermediate level radioactive waste is accepted in the repository.

Radiation limit: An upper limit is established for each major beta-gamma emitting radionuclide. An upper limit is also specified for long-lived alpha-emitting radionuclides.

Form of packaging:

Steel drums	100, 200, 400, 870 litres
Steel containers	5, 10 m^3
Cylindrical concrete containers	0.6, 1.2, 2 m^3
Cubic concrete containers	5 m^3

Inventory of LLW and ILW disposed of at the repository, by origin

Origin	Amount (m^3)	Total radioactivity*
Electricity sector	24 800	772 Gbq 256 TBq
Research facility	7 100	4 Tbq 51 TBq
Radioisotopes	1 000	0.1 Gbq 13 TBq
TOTAL	32 900	5 Tbq 320 TBq

* The upper and lower numbers are for LLW and ILW, respectively.

Reception capacity

Daily reception capacity is about 300 m^3; annual reception capacity is 35 000 m^3; and the total capacity is 1 000 000 m^3.

Safety requirements

Anticipated events for operational safety evaluation are fire and handling accidents. Anticipated events for post closure safety evaluation are human intrusion and water infiltration.

The dose limits shall not exceed the following values:

- during the operational phase: 20 mSv/year (over 5 years) for the operators and 1 mSv/year for the public;
- for the post-closure period: 0.25 mSv/year for the public, considering the most probable evolution scenario.

Other features

Surface of the repository: 0.3 km^2;
Number of cells: 39 (present), 420 (total);
Water management: the water collection system is designed to collect run-off and divert it to the storm basin. Another feature of this system is to collect leachate under the disposal structures, monitor it for radioactivity and treat it, if necessary, before discharge.

Costs

Cost elements	Cost (million French Francs)
Planning	115
Licensing	14
Construction: • before commissioning • during operation	 930 840
Operation per year	174.9

GERMANY

General

Policy

Since the early sixties, the radioactive waste disposal policy in the Federal Republic of Germany has been based on the decision that all kinds of radioactive waste are to be disposed of in deep geological formations, e.g. rock salt. Near-surface disposal is not practised in the Federal Republic because of a high population density, climatic conditions and the existence of appropriate deep-geological formations.

Regulations

The disposal of radioactive waste in a repository is governed, in particular, by the following specific regulations:

- Atomic Energy Act (Atomgesetz).
- Radiation Protection Ordinance (Strahlenschutzverordnung).
- Federal Mining Act (Bundesberggesetz).
- Safety Criteria for the Disposal of Radioactive Waste in a mine (Sicherheitskriterien).

The objectives for the construction and operation of a repository are prescribed by the Atomic Energy Act and the Radiation Protection Ordinance. The safety criteria specify the measures to be taken in order to achieve the disposal objective and define the principles that will demonstrate that this objective has been reached. The Federal Mining Act regulates all aspects relating to the operation of a disposal mine.

Pursuant to article 9b of the Atomic Energy Act, an application for the initiation of a plan approval procedure, i.e. a special kind of licensing procedure, has to be filed with the respective licensing authority of the Federal State. The objective of the plan approval procedure is to examine a project which is important for the region concerned, weighing and balancing the interests of the body responsible for the project as well as public and private interests affected by the planning, and to reach a decision which is legally binding against third parties. The plan approval procedure includes the participation of all authorities concerned and a public hearing. This procedure leads to the plan approval decision, i.e. the license.

Organisational structure

The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, BMU) is the competent authority for all aspects of spent fuel and radioactive waste management and the supervisory body for the licensing authorities in the Federal States. In carrying out its duties, BMU is advised by the Reactor Safety Commission (Reaktorsicherheitskommission, RSK) and the Commission on Radiological Protection (Strahlenschutzkommission, SSK).

The Federal Office for Radiation Protection (Bundesamt für Strahlenschutz, BfS) has been nominated by law as the competent authority for the construction and operation of federal installations for long-term storage and disposal of radioactive waste, acting on behalf of the Federal Government. In this respect, BfS is supervised by BMU.

The German Company for the Construction and Operation of Repositories for Wastes (Deutsche Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe mbH, DBE) is the main contractor for BfS.

The Federal Institute for Geosciences and Natural Resources (Bundesanstalt für Geowissenschaften und Rohstoffe, BGR) acts as consultant for BfS in geosciences.

The Federal States are the licensing authorities for repository projects.

Nuclear power generation

Data as of 31 December 1995 are as follows:

Total net capacity	22.1 GWe
Number of nuclear units	20
Nuclear electricity generated per year	154.1 TWh
Cumulated net electricity generation (1968-1996)	2 048.8 TWh

Information on the operating Morsleben repository and the planned Konrad repository

The Morsleben repository

General

The Morsleben facility is a repository for short-lived low and intermediate level radioactive waste with a low concentration of alpha-emitters. It was a repository in the former German Democratic Republic. Following the reunification of Germany in 1990, it was given the status of federal repository as defined in section 9a of the Atomic Energy Act. In February 1991, further disposal of radioactive waste was stopped to answer pending questions about safety and licensing. Resumption of operation began in January 1994. The operating license is limited by law to 30 June 2000.

Location

Morsleben repository is located near the village of Morsleben, north of the highway from Braunschweig to Berlin, just at the borderline between Lower Saxony and Saxony-Anhalt.

Operator

Morsleben repository is operated by the Federal Office for Radiation Protection (BfS), and the German Company for the Construction and Operation of Repositories for Waste Materials (DBE), as main contractor for BfS, carries out the operation.

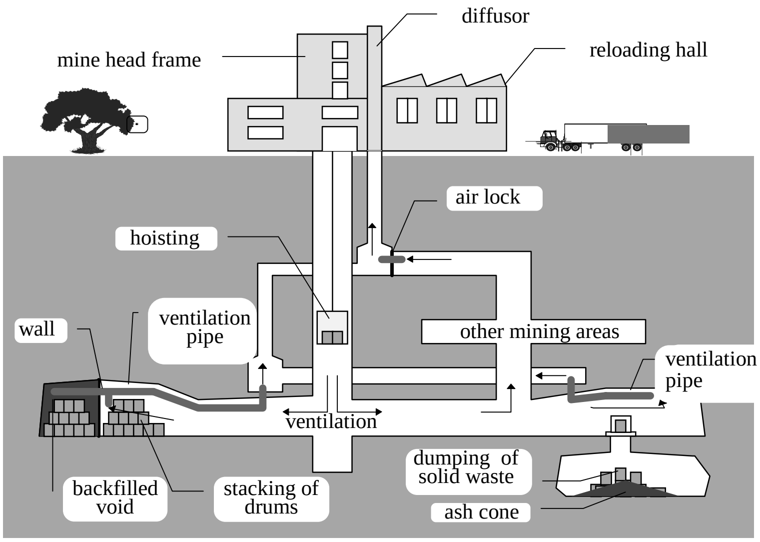
Type of repository and geological formation

Morsleben repository is of a deep geological formation type, in sedimentary rock salt. It is an abandoned salt mine. Retrievability is not necessary.

The repository is situated in a Zechstein salt structure. The salt structure is built from halite with layers of anhydrite, potash and saliferous clay.

Its depth is approximately 500 metres below ground level and 372 metres above sea level; groundwater level is at approximately 500 metres. The open volume of the mine is about 5.5 x 10^6 m^3.

Figure A2.4 **Schematic view of Morsleben repository, Bartensleben shaft**



Technical description

Morsleben repository (Figure A2.4), an abandoned Bartensleben salt mine, has one shaft for the transport of waste packages, underground operating staff, equipment and material. Only the open chambers of the deepest level (4th level) are used for final disposal.

The waste packages are delivered in containers to Morsleben repository by truck shipment. In the reloading hall, the containers are transferred by bridge crane or fork lift. After entry control, the waste packages, mostly 200 to 600-litre drums, are placed by fork lift onto a loading car. The waste packages are transported along the shaft to the fourth underground level, and are placed in the designated emplacement rooms, where they are stacked or dumped, depending on the category of waste.

Drums are stacked in up to four layers, with a maximum height of about 4.5 metres. Dumping of waste from shielded transport casks (primary containers) is performed either by crane or fork lift above the dumping device, into the emplacement room.

When the emplacement room is filled with waste packages, the remaining space is backfilled with lignite filter ash.

Types, origins and amounts of radioactive waste

Morsleben repository accepts LLW and special categories of ILW. The categorisation of radioactive waste considers both types of waste (according to their material properties) and the so-called radiation protection groups (according to their radiological characteristics). Under this classification, radioactive wastes are listed as solid wastes (waste category A1) according to their material properties, and as spent sealed radiation sources, occurring as waste (waste category A3). The classification by so-called radiation protection groups (S1-S5) is based on the dose rate at the unshielded surface of solid wastes, or on the activity of the spent sealed radiation sources. Another aspect for classification of solid wastes in radiation protection groups is the activity concentration of beta/gamma-emitters per m^3. The activity concentration of alpha-emitters is limited to 4×10^8 Bq/m^3 for all solid wastes.

Radioactive waste of the S1 and S2 radiation groups can be considered as LLW and those of radiation groups S3, S4 and S5 as ILW. Heat generating ILW, e.g. originating from spent fuel reprocessing, is not accepted in Morsleben.

Categorisation of radioactive waste

Radiation Protection Group	Solid Waste A1		Sealed Radiation Source A3
	Dose rate (mSv/h)	Activity concentration (β,γ GBq/m^3)	Activity (GBq)
S1	≤ 2	≤ 4	≤ 0.2
S2	2 to 10	4 to 40	0.2 to 2
S3	10 to 100	40 to 400	2 to 20
S4	100 to 500	400 to 4 000	20 to 200
S5	500 to 1 000	4 000 to 40 000	

Volume and inventory of waste disposal*

Period	Volume and inventory			Cumulated volume and inventory		
	LLW (m^3)	ILW (m^3)	Total radioactivity (Bq)	LLW (m^3)	ILW (m^3)	Total radioactivity (Bq)
1971 – 1977[1]	601		3.2×10^{11}	601		3.2×10^{11}
1978 – 1982	6 024		1.7×10^{13}	6 625		1.7×10^{13}
1983 – 1987	5 458		5.4×10^{13}	12 083		7.1×10^{13}
1988 – 1991	2 007	362	7.5×10^{13}	14 452		1.6×10^{14}
1994 – 1996	11 047	115	3.9×10^{13}	25 614[2]		2.0×10^{14}
1997 – 2000	28 000	2 000	1×10^{16}	54 000		1×10^{16}

1. Test emplacement.
2. Plus 6 583 spent sealed radiation sources.
* There is no distinction between VLLW and LLW. ILW is treated separately.

Reception capacity

The annual number of operating days is 200. Daily reception capacity for each type of waste is 34 m^3 for S1 and S2 (drums), 8 m^3 for S3-S5 (re-usable containers) and 27 m^3 for miscellaneous delivery. In 1995, an average of 22 m^3 of S1-S3 were disposed of per day. A total of 4 326 m^3 were disposed of in 1995. Total capacity of the repository until 30 June 2000 will be about 54 000 m^3.

The planned Konrad repository

General

The planned Konrad repository is decisively influenced by political issues and German licensing procedure, the so-called plan approval procedure, with its increasing requirements. The estimated licensing lead time is about 15 years. The important steps of the licensing procedure are described below.

Between 1975 and 1982, the geological and mining situation of the Konrad iron-ore mine was investigated for possible disposal of radioactive waste. On 31 August 1982, following the positive conclusion of these investigations, an application for the initiation of a licensing procedure was made with the plan approval authority. After a comprehensive programme of underground exploration from 1983 onwards, according to the Safety Criteria for Disposal of Radioactive Waste in a Mine and above-ground investigations, comprehensive documents were submitted in 1986 to the plan approval authority, the Ministry for Environment in Lower Saxony (Niedersächsisches Umweltministerium, NMU). The plan approval procedure requires that the documents be made available to the public; this took place in 1991, at five locations in Lower Saxony. During a public inquiry between 25 September 1992 and 6 March 1993, oppositions to the plan documents from 290 000 members of the public were discussed. Requirements from all authorities concerned led to multiple revisions of the licensing documents.

Location

Konrad repository is located in Salzgitter-Bleckenstedt, near Braunschweig, in Lower Saxony.

Operator

Konrad repository will be operated by the Federal Office for Radiation Protection (BfS); the German Company for the Construction and Operation of Repositories for Wastes (DBE), as main contractor for BfS, will carry out the operation.

Type of repository and geological formation

Konrad repository is of a deep geological type, in sedimentary iron-ore formation. It is an abandoned iron-ore mine. Retrievability is not necessary.

The repository is situated in a former iron-ore mine (oolithic iron ore; deposit of the Minette type), in an oxfordian (Upper Jurassic) host rock. The footwall of the mine is made up of sediments of the Dogger (Middle Jurrassic), Liassic (Lower Jurrassic) and Triassic (Keuper, Muschelkalk and Bunter) rocks. The hanging wall comprises clay and marlstones of the Kimmeridgian (Upper Jurrassic) age, covered by clay stone from the lower cretaceous, several hundred metres in thickness. This clay stone is the geological barrier for the repository.

Its depth is approximately 1 000 to 1 300 metres below ground level and 900 to 1 200 metres below sea level; groundwater level is at about 1 000 to 1 300 metres.

Technical description

The main feature of the technical design of the planned Konrad repository, including the scheduled mode of operation, is keeping the mining activities strictly separate from the disposal operations. According to the Safety Criteria, the number of shafts are to be kept to a minimum, although at least two shafts are necessary for transport, ventilation and safety reasons. Consequently, only two shafts will be in operation at Konrad repository. The downcast ventilation shaft, Konrad 1, is planned to be used for the transport of the iron ore excavated during the construction of the disposal rooms, for the transport of equipment, material and man-riding. The upcast ventilation shaft, Konrad 2, is to be used for the transport of the waste packages to be disposed of and the operating staff working at the bottom of the shaft.

It is foreseen to deliver the waste packages as separated transport units via rail or truck shipment. A transport unit consists of one box-shaped container or one pool pallet loaded with up to two cylindrical waste packages. In the reloading hall, the transport units are put into a shaft conveyance loading car. This loaded platform car is subsequently transported to the radiation protection measuring installations where entry control of the waste packages takes place.

After entry control, the shaft conveyance loading car is driven into the shaft hall where it is loaded on to the hoist cage and then lowered to the shaft bottom, at the 850-metre level. The waste packages are then transported by a further two different carriers from the shaft bottom to the designated disposal room.

The voids will be backfilled in sections about 50 metres in length, with concrete grout based on crushed host rock material, during operation of the repository.

Types, origins and amounts of radioactive waste

The planned Konrad repository is designed to accept all types of radioactive waste with negligible heat generation, i. e. waste packages which do not increase the host rock temperature by more than 3 K on average. Therefore, according to the German radioactive waste disposal concept, wastes from decommissioning can also be emplaced in the repository. The maximum inventory will have a total activity of about 5×10^{18} Bq and an activity of alpha-emitters of 1.5×10^{17} Bq.

Reception capacity

Annual number of operating days will be 200. Daily reception capacity will be about 180 m^3. Design capacity is 650 000 m^3.

COSTS

(million German Marks, DEM)

MORSLEBEN

Planning and licensing		**Construction**		**Operating** (per year)		**Closure**		**Miscellaneous**	
				Administration	3.16			Communication	N.A.
				Handling	0.95			Public relations	N.A.
				Filling[1]				Economic incentives	N.A.
				Others[2]	24.10				
				Radioactivity monitoring	0.66				
				Number of staff	173				
Total	**N.A.**	**Total**	**N.A.**	**Total**	**28.87**	**Total**[3]	**N.A.**	**Total**	**N.A.**

KONRAD

Planning and licensing		**Construction**		**Operating** (per year)		**Closure**		**Miscellaneous**	
Total	**1 070.3**[4]	**Total**	**1 463.3**[5]	**Total**	**68.00**	**Total**	**220**	**Total**	**N.A.**

Repository	**Morsleben**	**Konrad**
Capacity of the repository	54 000 m^3	650 000 m^3
Annual rate of waste delivery	5 000 m^3	16 250 m^3

Exchange rate as of 1 July 1995
1.38 DEM = 1 US$

Notes:

1. Included in the handling cost. N.A. = Not available
2. Includes salaries, energy, maintenance, site security, insurance, etc.
3. The concept of the closure has not yet been decided.
4. The cost includes 15-year lead time of licensing procedure and the costs for keeping the mine open until the beginning of construction.
5. The cost includes civil engineering, investments and the costs for keeping the mine open during the construction phase.

HUNGARY

General

Sources, types and quantities of wastes

The majority of the LILW that is generated in Hungary arises from the operation of Paks NPP. Much less radioactive waste, in terms of volume, is generated by small-scale isotope users.

Nuclear power plant waste

Evaporator concentrates: Waters of high salinity are treated by evaporation. The annual production has so far been 200-250 m^3 for the four units.

Spent ion-exchange resins: Waters of low salinity leaving the process cycle are cleaned through ion-exchange lines. Average production of spent ion-exchange resins is 0.6 m^3/y for the four units.

Dry active wastes: Compactible solid LLW is collected in 50-litre welded polythene bags, compacted and placed in 200-litre steel drums. Metal LILW with sharp edges is collected directly in drums. The waste is compacted into metal drums of 200 litres, using a compactor with a pressing force of 500 kN. The annual production after compacting is less than 100 m^3 for the four units.

Non fuel cycle waste

Nowadays, the number of non fuel cycle institutions is about 500-600, which produce yearly about 60 m^3 LILW (50-60 m^3 solid, 4-5 m^3 liquid, 1-2 m^3 biological waste and 500-1 000 pieces spent radiation sources).

Classification

According to the Hungarian standard the waste classification on the basis of activity concentration is the following:

	Activity concentration (kBq/kg)	Surface dose rate
Low level	$< 5 \times 10^5$	< 300 μGy/h
Medium level	5×10^5 to 5×10^8	300 μGy/h to 10 mGy/h
High level	$> 5 \times 10^8$	> 10 mGy/h

If the determination of the radioactive concentration of solid waste could not be applied in connection with reactor and accelerator facilities, and apart from alpha bearing waste, then the base of surface dose rate measurement is accepted for classification.

Competent bodies

Nuclear activities have so far been regulated by Act Nr. 1 of 1980, but it will be replaced in June 1997 by the new Act, Nr. CXVI of 1996, on Atomic Energy.

According to the Act; the establishment of a new nuclear facility or radioactive waste disposal facility, as well as the addition of a further unit containing a nuclear reactor to an existing nuclear power plant, requires the prior approval of the Parliament.

It is the Government's task to control and supervise the safe application of atomic energy. The Government provides for the execution of these tasks through the Hungarian Atomic Energy Commission (an advisory and control body of the Government) and the Hungarian Atomic Energy Authority (hereinafter HAEA) as well as the Ministers concerned.

HAEA is the independent regulatory body in the nuclear safety field responsible among others for the licensing of nuclear facilities (NPP, research reactor), whereas radiation safety lies in the competence of the Minister of Public Welfare.

The Ministry of Public Welfare is responsible for the disposal of radioactive waste as well as for the development and implementation of radiation standards. Waste collection, handling and treatment of the site of nuclear facilities and international transportation, packaging and recording of radioactive materials are regulated by the HAEA. According to the new 1996 Act, the Parliament's prior approval is required to initiate the establishment of a radioactive waste disposal facility. The Ministry of Public Welfare performs the licensing and controlling of the siting, construction, operation, etc., but in the licensing procedure it must co-operate with other authorities.

The Central Nuclear Financial Fund will be set up in 1998 for financing the construction and operation of facilities for the final disposal of radioactive waste as well as for the interim storage and final disposal of spent fuel, and the decommissioning of nuclear facilities.

Details of existing disposal site

Prior to 1976 radioactive waste was disposed of at a facility located in Solymár, near Budapest. After the new facility at Püspökszilágy was commissioned, Solymár burial facility was dismantled, the waste was removed and transported to Püspökszilágy and the site was reclaimed.

In 1976, the radioactive waste management and disposal facility at Püspökszilágy was opened to condition and eventually to dispose of institutional waste. The near-surface, concrete trench-type facility is divided into four areas in order to dispose of different types of wastes separately. The disposal area originally destined for bags and drums had to be extended since the original capacity was filled. This additional capacity ensures disposal availability for institutional waste for more than forty years.

Because there has not been a final disposal site for radwaste from Paks NPP, the Püspökszilágy disposal site has temporarily received and disposed of nuclear radwaste with restricted conditions (waste type, activity contents and package). Up to 1996, a volume of 4 500 m^3 solid and solidified waste was emplaced in the disposal site, 2 100 m^3 of which originates from Paks NPP.

LLW/ILW disposal for nuclear power plant wastes

Most R&D carried out in Hungary on LILW is aimed at identification of a suitable site for either a near-surface or a mined cavity-type repository. Based on the results of the geological survey, the preliminary safety analyses and the public acceptance, the Board of the National Programme had selected two from the potential geological objects, where exploratory surveys were carried out:

- the granite formations near Bátaapáti-Üveghuta for geological repositories;
- the loess formation near Udvari for near- surface repositories.

The detailed exploration work in Bátaapáti-Üveghuta will begin in the second part of 1977.

Nuclear Power Generation

Total nuclear capacity	1.84 GWe
Load factor	0.87
Number of nuclear units	4
Nuclear electricity generated in 1995	14.03 TWh
Cumulated nuclear electricity generation (1983-1995)	141.8 TWh

Information on the repositories

The existing repository (Püspökszilágy, Figure A2.5)

Name and location

Radwaste Treatment and Disposal Facility, situated at Püspökszilágy, 15 km south-east of Vác and about 30 km north of Budapest.

Beginning of construction	1974
Completion of construction	06/12/1976
Opening of the site	01/09/1976
First disposal	01/03/1977

Operator

State Public Health and Medical Officer Services (state-owned).

Type

Vault (no retrievability requirement).

Waste emplacement method: waste contained in drums (200 and 350 litres) and plastic bags (30 litres).

Method of vault: near-surface concrete vaults with engineered barriers.

Geological formation

Above groundwater level: 25 metres; 25-30 metre deep clay and loess with clay ($k = 10^{-6}$ to 10^{-8} cm/sec), montmorillonite content: 24 per cent.

Depth from ground level: 6 metres; height from sea level: 240 metres.

Types, origins and amounts of radioactive waste

The repository accepts LILW and spent sources; upper radiation limits for the repository are 10 mGy/h for NPP waste and 50 mGy/h for others.

Inventory of LLW disposed of at the repository by origin

(as of 1 July 1995)

Origin	Amount (m^3)	Emission	Total radioactivity (Bq)
NPP	2 100	β,γ	3×10^{12}
Research facility Radioisotopes • production • medical uses	2 400	α,β,γ	2.1×10^{12}
Spent sources	0.54	α,β,γ	3.1×10^{15}
TOTAL	4 500	α,β,γ	3.1×10^{15}

Capacity and inventory of the repository with time scale

Period	Capacity (m^3)		Inventory of waste disposed of at the repository		
	LLW	ILW	LLW (m^3)	ILW (m^3)	Total radioactivity (Bq)
1977-1981	3 300	1.0	1 160	}	2×10^{14}
1982-1986	3 300	1.0	2 380	}	8×10^{14}
1987-1991	3 300	1.0	3 300	} 0.54	1.2×10^{15}
1992-1995	5 000	1.0	4 500	}	0.9×10^{15}
TOTAL	5 000	1.0	4 500	0.54	

Daily reception capacity of each type of waste

	Designed	Actual average of the last five years
Spent sources	unlimited	7.2 pieces
Drums	12 m^3 (35 pieces)	0.8 m^3 (2.2 pieces)
Plastic bags	8 m^3	0.6 m^3

Safety requirements

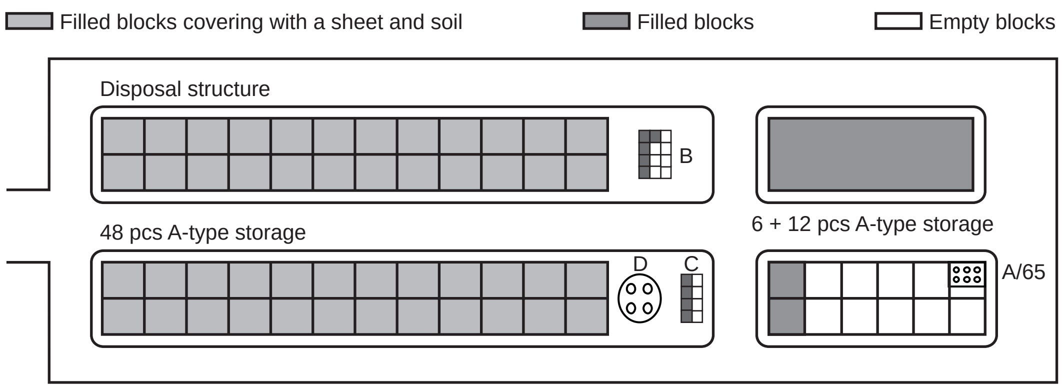
Anticipated events for safety evaluation are intrusion, earthquake and water flood. Guards provide security against intrusions and water movements are monitored. The disposal site is placed at the top of a hill, 25 metres above water flood level. The dose limit rates are 10 mGy/h for NPP waste and 50 mGy/h for others.

Other features

Surface of the shallow repository	0.11 km^2
Number of the trenches	4
Number of cells	66

Rain water is collected from concrete ditches into a basin. After control, it is led into a small stream. Leakage is managed by monitoring in wells. The annual number of operating days is 240 as operation (transportation) can be delayed by heavy snow.

Figure A2.5 **Püspökszilágy disposal site**



A. 66 pieces (60 x 70 m^3 + 6 x 140 m^3) concrete blocks for drums and bags.
B. Pits (volume: 420 litres) for spent sources.
C. Blocks for spent solvents (12 m^3).
D. Pits (volume: 750 litres) for low active spent sources.

Information on the planned repository (Üveghuta)

Location

Üveghuta, 13 km south of Bonyhád.

Time schedule

Construction will start in 1999 and finish in 2005.

Operator

National Agency for Radwaste Management (state-owned).

Type

Subsurface (retrievability is required). Waste contained in drums and concrete containers is placed into an underground vault with engineered barriers.

Geological formation

70 metres loess from the surface, in deeper granite; depth from ground level: 100-150 metres; height from sea level: 200 metres. Below groundwater level is 100 metres.

Types, origins and amounts of radioactive waste

The repository will have capacity for 20 000 m^3 of LILW from operation plus 20 000 m^3 from decommissioning.

Safety requirements

Anticipated events for safety evaluation are intrusion, earthquake, water flood.

Other features

Deep geological sites. Length and total volume of the cavern: 22 x 200 m; 80 000 m^3.

Information on the planned repository (Udvari)

Location

Udvari, 7 km north of Gyönk.

Time schedule

Construction will start in 1999 and finish in 2005.

Operator

National Agency for Radwaste Management (state-owned).

Type

Shallow vault (retrievability is required). Waste contained in drums and concrete containers is placed into a near-surface concrete type vault with engineered barriers.

Geological formation

150-metre deep loess with clay content. Depth from ground level: 5 metres; height from sea level: 178 metres; and height from groundwater level: 35 metres.

Types, origins and amounts of radioactive waste

The repository will have capacity for 20 000 m^3 of LILW from operation plus 20 000 m^3 from decommissioning.

Safety requirements

Anticipated events for safety evaluation are intrusion, earthquake, water flood.

COSTS

(million Hungarian Forint, HUF)

PÜSPÖKSZILÁGY							
Planning and licensing		**Construction**		**Operating** (per year)		**Miscellaneous**	
Planning[1]				Administration	27.70	Economic incentives[3]	14.5
Licensing	Not applicable			Handling	13.50		
				Overpacking	0.40		
				Backfilling	0.85		
				Others	1.20		
				Radioactivity monitoring	4.25		
				Number of staff[2]	45		
Total		**Total**	**560**	**Total**	**47.90**	**Total**	**14.5**

Operating costs during institutional control of the repository	
Radioactivity monitoring	3.4

Exchange rate as of 1 July 1995

125.84 HUF = 1 US$

Capacity of the repository	5 000 m^3
Annual rate of waste delivery	237 m^3

Notes:

1. Included in construction costs.
2. Including 21 security guards.
3. Only for the last year.

COSTS *(contd.)*

(million Hungarian Forint, HUF)

ÜVEGHUTA

Planning and licensing		Construction		Operating (per year)	
R&D	870	Design	620		
		Vault	1 460		
Licensing	300	Others[4]	1 490		
		Extension	2 180		
		Facilities	1 460	Number of staff	75
Total	**1 170**	**Total**	**7 210**	**Total**	**480**

Capacity of the repository	40 000 m^3
Annual rate of waste delivery	1 140 m^3

Note:

4. Including property, waterworks, electrical network, environmental monitoring system, restoration of roads, etc.

UDVARI

Planning and licensing		Construction		Operating (per year)	
R&D	740	Design	360		
		Vault	980		
Licensing	170	Others[5]	1 060		
		Extension	1 000		
		Facilities	1 600	Number of staff	60
Total	**910**	**Total**	**5 000**	**Total**	**354**

Capacity of the repository	40 000 m^3
Annual rate of waste delivery	1 140 m^3

Operating costs during institutional control of the repository	
Radioactivity monitoring	7.2

Exchange rate as of 1 July 1995

125.84 HUF = 1 US$

Note:

5. Including property, waterworks, electrical network, environmental monitoring system, etc.

ITALY

Since 1962, ENEL has operated 4 nuclear power plants. The nuclear power plants were closed down in the 1980s, following decisions made by the Italian government after the Chernobyl accident. These government decisions also blocked the construction of Montalto di Castro (2 x 1 000 MWe BWR) and Trino 2 (2 x 1 000 MWe PWR) nuclear power plants, whose operation was scheduled to start in the 1990s.

The following sections summarise the main aspects of Italian regulation on the management of radioactive waste.

Italian radioactive waste management regulation

The first Italian specific regulation concerning radioactive waste management was issued in 1985 (draft) by ENEA-DISP. This regulation is described in Technical Guide No. 26 which sets out criteria and requirements for proper waste management (i.e. collection, selection, treatment, conditioning, interim storage, transportation and disposal of radioactive waste).

The 1987 edition of Technical Guide No. 26 states that radioactive waste management shall be based on fundamental principles of health and environment protection of workers and population, taking into account the impact on future generations as well as aspects which have or might have adverse effects on the quality of the environment and on the present and future use of land.

The following sections summarise the main aspects of Technical Guide No. 26, which are relevant to the management of radioactive waste.

Radioactive waste classification

As radioactive waste produced by the peaceful use of nuclear energy has different forms, radioactivity contents and emitted radiation, its criteria must be defined according to waste characteristics. For this purpose, Technical Guide No. 26 classifies radioactive waste into three categories according to radiological characteristics (radionuclides contained in the waste and their concentrations).

First category waste is a radioactive waste that, within a few months or a few years at the most, decays to radioactivity concentration lower than the values[1] specified by the Italian law for

1. These values are not available yet and have to be defined by the competent Italian authorities.

disposal waste into the environment. The presence of long half-life radionuclides is permitted, provided their concentration is lower than the above mentioned values.[2]

The second category comprises a waste that, in periods of time varying from a few decades to a few centuries, decays to radioactivity concentration in the order of some hundreds of Bq/g; the presence of very long half-life radionuclides is permitted provided their concentration is of this order of magnitude. Second category waste is mainly generated in nuclear facilities (primarily during operation of nuclear power plants) and in a few biomedical, industrial and research activities. This category also includes some parts and components arising during nuclear power plant decommissioning.

Third category waste is a radioactive waste which does not belong to the previous categories. It covers waste that needs thousands or more years to decay to a radioactivity concentration of some hundreds of Bq/g. The third category includes high-level waste, arising during spent fuel reprocessing and other research and industrial activities, which also contains alpha and neutron emitters.

First category radioactive waste management

First category radioactive waste must be kept in an appropriate store long enough to reach concentration values lower than those for disposal into the environment.[3] If its radioactivity concentration is lower than these values, first category waste may be directly disposed into the environment, in accordance with the Italian law concerning hazardous waste (implementation of Council Directive 78/319 concerning toxic and hazardous waste).

Requirements for second category radioactive waste disposal

The following criteria apply to land disposal (above ground surface or shallow-land burial) of second category radioactive waste; however most of them may also apply to other methods of land disposal such as in mines or natural cavities.

Radioactive waste land disposal shall comply with the criteria for radiological and environmental protection. More specifically, the present and future exposure of the population reference group shall not exceed an effective dose equivalent of 0.1 mSv/year, which is a small fraction of the level of exposure from average natural background radiation. Consequently, technical requirements for waste interim storage facility and disposal site shall be adequately selected; administrative provisions should be envisaged at the design phase of the disposal facility and within waste management procedures.

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2. Practically, first category waste is a radioactive waste that contains essentially short-lived radionuclides whose half-life is lower than one year and, in most cases, lower than two months. Waste of this type is mainly generated in biomedical and research activities.

3. See footnote 1.

Second category waste is divided into two groups according to its radiological characteristics (radionuclides contained in the waste and their concentrations):

Group 1: waste which must be conditioned[4] before its disposal.
Group 2: waste which does not need conditioning.

For second category – group 1 waste, concentrations of radionuclides in a conditioned waste shall not exceed the limits for disposal listed in Table 1. Such values, which do not exceed the concentration limits set down by NEA regulation for sea-dumping, are referred to the whole monolithic volume in which the radioactive waste is distributed (for example shielding material placed inside the package shall not be considered in determining the concentration of radionuclides). In the case of a mixture of radionuclides, the sum of the fractions obtained by dividing each radionuclide concentration by the corresponding limit, shall not be higher than 1.

Table 1. **Concentration limits for second category conditioned waste disposal**

Radionuclide	Concentration limit (Bq/kg)
Radionuclides with $T_{1/2} \leq 5$ years	37×10^9
Alpha emitters with $T_{1/2} > 5$ years	370×10^3*
Beta-gamma emitters with 5 years < $T_{1/2} \leq 100$ years	37×10^6
Beta-gamma emitters with $T_{1/2} > 100$ years	370×10^3*
Beta-gamma emitters with $T_{1/2} > 100$ years, in activated metals	3.7×10^6
^{137}Cs and ^{90}Sr	3.7×10^9
^{60}Co	37×10^9
^{3}H	1.85×10^9
^{241}Pu	13×10^6
^{242}Cm	74×10^6
(*) Average concentration of the waste contained in the disposal site (3.7×10^6 package maximum)	

The conditioned waste shall have such mechanical, physical and chemical characteristics as to make it suitable for land disposal; it shall, in any case, comply with the packaging requirements established by NEA Guidelines for sea-dumping and by national and international regulations on transportation of radioactive materials (particularly IAEA or UN regulations).

4. "Conditioning" is a process carried out by means of a solidifying agent within a container to obtain a final package (conditioned waste and container) in which the radionuclides are encapsulated in a solid matrix in order to limit their potential mobility.

The minimum requirements for conditioned waste have to be checked by applying the following tests:

a) compressive strength;
b) thermal cycling;
c) radiation resistance;
d) fire resistance;
e) leaching rate;
f) free liquids;
g) biodegradation resistance;
h) immersion resistance.

The required tests shall be performed within a documented programme for qualification and control of the conditioning process. This programme which is developed according to the applicable Quality Assurance requirements, is divided into two parts. Scope of the first part of the programme is to perform the tests for conditioning process qualification and to point out the quality-related parameters influencing the quality of the conditioned waste. The second part of the programme deals with the procedures for the control of quality-related parameters in order to assure the required quality of the conditioned waste, during conditioning activities.

As far as second category – group 2 waste is concerned, dry solid waste which, even following a volume reduction process, contains radionuclides with concentrations lower than the limits listed in Table 2, and which therefore requires times of few decades to decay to radioactivity concentration in the order of some hundreds of Bq/g, may be land disposed, in compliance with radiological and environmental protection objectives, without any conditioning. Decommissioning waste (DAWs), which generally consist of slightly activated or contaminated material, belong to this group of waste. For land disposal of such waste, its chemical and physical nature, the treatment process, the packaging technique adopted and the presence of free liquids shall be considered. This waste shall be packaged into containers and, at the disposal facility, separated from the conditioned waste packages.

Table 2. **Concentration limits for second category non-conditioned waste disposal**

Radionuclide	Concentration limit (Bq/kg)
Radionuclides with $T_{1/2} \leq 5$ years	18.5×10^6
Radionuclides with $T_{1/2} > 5$ years	370×10^3
^{137}Cs and ^{90}Sr	740×10^3
^{60}Co	18.5×10^6

Requirements for second category radioactive waste final disposal facility

Since a site for radioactive waste final disposal has not been chosen yet, there are no specific requirements for the final disposal facility. General requirements for a second category radioactive waste final disposal site are set down in the Technical Guide No. 26.

Disposal site hydrogeological characteristics shall minimise waste leaching by groundwater and possibility of diffusion of contaminated water to the biosphere.

The climatic, geographical and geomorphological characteristics of the disposal site shall exclude significant erosion processes as well as land-sliding and flooding possibility.

Areas shall be avoided where significant tectonic processes, seismic activity or vulcanism could reduce waste confinement capability.

Disposal site geological and hydrogeological characteristics shall be sufficiently homogeneous so that the surveys and analyses performed on the site are representative of the site itself.

Disposal site selection shall be made taking into account land use and human activities or man made facilities (e.g. dams) whose failure could adversely modify site characteristics.

Disposal site and/or disposal facility shall be provided with engineering features capable to prevent or delay a direct contact between the waste and the environment which can result in a radioactivity release. The design of these features shall, as far as possible, avoid maintenance.

An environmental monitoring system shall be provided at the disposal site. Environmental surveillance shall be maintained even after the disposal period is over.

JAPAN

General

In Japan, the basic framework for nuclear research, development and utilisation, including regulation for those activities, is set out in the Atomic Energy Fundamental Law. According to the framework, the Atomic Energy Commission (AEC) is in charge of deciding on national policy and strategy for those activities that involve radioactive waste disposal and in 1956, it formulated the first Long-Term Programme for Research, Development and Utilisation of Nuclear Energy in Japan. Since then, the programme has been revised approximately every 5 years by AEC and the last revision was made on 24 July 1994.

Policies regarding disposal of radioactive waste are defined in the programme. Radioactive waste disposal is controlled mainly by the Regulative Act for Nuclear Source Materials and Nuclear Reactor (hereinafter referred to as “Reactor Regulation Law”) or the Act for the Prevention of Radiation Hazards due to Radioisotopes, etc. (hereinafter referred to as “Radiation Hazard Prevention Law”) according to the original kind of facilities.

Various administrative agencies are in charge of regulation, and a number of laws, orders and standards are established to ensure safety for radioactive waste disposal. The Radiation Council was set up to harmonise technical standards for the prevention of radiation hazards. The Nuclear Safety Commission (NSC) has special tasks for the formulation and maintenance of guides.

With regard to the radioactive waste disposal system, only the land disposal system has been adopted for LLW generated from nuclear power plants, controlled by the Reactor Regulation Law, but it has not yet been authorised by the Radiation Hazard Prevention Law.

LLW shall be disposed of:

1) by solidifying the waste in a container and disposing the containers in shallow ground of waste burial facilities where artificial structures are constructed, or

2) by placing nuclear concrete waste, not solidified in a container, in shallow ground of waste burial facilities where no artificial structures are constructed.

There are upperbounds of radioactivity concentration of LLW which can be disposed of in these facilities.

The first type of facility (1) is commercially operated by Japan Nuclear Fuel Limited (JNFL) at Rokkasho-mura and has been so since 1992. The facility currently has permission for the disposal of 200 000 drums of 200-litres each of LLW from nuclear power plants and is called No. 1 disposal facility. LLWs which can be disposed of at the facility are concentrated waste, spent resin, sludge and ash (including palletised waste) which are uniformly and homogeneously mixed with cement, plastic or asphalt solidifying material. The cumulative amount of radioactive waste from nuclear reactors was about 563 400 drums at the end of March 1995, of which 49 600 drums have already been shipped to the disposal facility. JNFL applied for a license for a further disposal capacity of 200 000 drums as of January 1997 and this one is called No. 2 disposal facility. The facility will accept dry active wastes, mainly metals such as pipes and angles, immobilised with mortar.

The second type of disposal facility (2) is operated by Japan Atomic Energy Research Institute (JAERI). To demonstrate the safety of VLLW disposal, about 1 670 tons of very low-level concrete waste generated from Japan Power Demonstration Reactor (JPDR) are disposed of in the facility.

There is no definite threshold for LLW and VLLW, but they are regulated by upperbounds of radioactivity concentration for land disposal as mentioned above.

Exemption level of radioactive waste has not yet been established.

Nuclear power generation

Data as of 31 March 1995 are as follows:

Total gross nuclear capacity	40.4 GWe
Number of nuclear units	48
Nuclear electricity generated in 1994	269 TWh
Cumulated gross nuclear electricity generation (1966-1995)	2 818.3 TWh

Information on the repository

Name and location

Rokkasho low-level radioactive waste disposal centre, facilities Nos. 1 and 2. These are situated at Rokkasho-mura, Kamikita-gun, Aomori, 30 km north of Misawa City. Close to the repository, there are other nuclear facilities for waste management and reprocessing as well as a uranium enrichment plant.

Status

No. 1 disposal facility is being operated.
No. 2 disposal facility is under application for license.

Time schedule

See Section 2.3.10 of the report.

Operator

The repository is operated by Japan Nuclear Fuel Limited (JNFL).

JNFL is a private company; 71 per cent of its stock is shared by Japanese utilities. JNFL is also in charge of reprocessing, uranium enrichment and interim storage of HLW returned from abroad.

Type

No. 1 disposal facility (Figure A2.6): the repository is a shallow ground vault-type, below groundwater table. Retrievability is not required. There are 8 burial facility groups, each of which can bury about 5 000 m^3 of waste (equivalent to about 25 000 drums of 200-litres each), thus totalling 40 000 m^3 of waste. Each burial group consists of 5 vaults accommodating about 1 000 m^3 (approximately 5 000 drums) of waste. Each vault of reinforced concrete is 24 m x 24 m x 6 m high in size and internally divided into 16 cells, each of which can accept 320 drums. LLW solidified with cement and other materials and encapsulated in a 200-litre steel drum is placed in a reinforced concrete cell. The spaces between the drums are then sealed by a cement-based mortar grout. Once the reinforced concrete lid is formed, these burial facilities are backfilled by a bentonite-soil mixture up to the same level as the rock and then by soil more than 4 metres thick, covering the bentonite-soil mixture. Furthermore, a porous concrete layer will be provided on the inside of the outer walls of the vaults to prevent the entrance of groundwater. If underground water were to permeate into the vault through the outer wall, its water would pass through this porous concrete layer and be discharged into the inspection tunnel outside the burial facilities.

No. 2 disposal facility: the type of repository is essentially the same as No. 1 disposal facility. There are also 8 burial facility groups, each of which can bury about 5 000 m^3 of waste (equivalent to about 25 000 drums of 200-litres each), thus totalling 40 000 m^3 of waste. However, each burial group consists of 2 vaults accommodating about 2 600 m^3 (about 13 000 drums) of waste. Each vault of reinforced concrete is about 36 m x 37 m x 7 m high in size and internally divided into 36 cells, each of which can accept 360 drums.

Geological formation

No. 1 disposal facility: the Neogene Takahoko formation is present in and around the location of the disposal facility and is covered by the quarternary layer composed of terrace deposit, volcanic ash deposit, and alluvial deposit. The Takahoko formation which forms the supporting base of the facility is base-rock with a sufficient bearing capacity (according to a standard penetration test, N-value is greater than 50) and low permeability, conditions that make it suitable for waste disposal. While two faults are observed in and around the location of the disposal facility, they have been stable for a long time. Studies of the faults indicate that they will not affect the stability of the supporting base of the facilities or the flow of underground water. The depth from ground level is approximately 14 to 19 metres and 26 to 32 metres above sea level. The disposal facility is a few metres below ground water level.

No. 2 disposal facility: the geological formation is the same as No. 1 disposal facility except that the depth from ground level is approximately 16 to 21 metres and the height above sea level is approximately 31 to 36 metres. The disposal facility is also a few metres below groundwater level.

Types, origins and amounts of radioactive waste

Types: LLW is accepted in the repository.

Radioactivity limit: the incoming maximum radioactive concentration and total activity contained in the LLW to be brought in for disposal vary according to the radionuclides concerned.

Form of packaging: only 200-litre drums are used.

Inventory of LLW disposed of at No.1 repository is 9 408 m^3 (9.7 x 10^{12} Bq), all of which come from the electricity sector, as of 31 March 1995.

Reception capacity and inventory

No. 1 disposal facility: capacity of the repository is 20 000 m^3 and 8.7 x 10^{14} Bq, and accumulated inventory is 9 408 m^3 and 9.7 x 10^{12} Bq, as of 31 March 1995. The final capacity will be 40 000 m^3.

No. 2 disposal facility: the final capacity of the repository will be 40 000 m^3 and 1.7 x 10^{15} Bq after 2000.

Daily and yearly reception capacities are 64 m^3 and 5 000 m^3 respectively, for each disposal facility .

Safety requirements

1. Anticipated events for safety evaluation: According to the "Fundamental Siting Conditions", an assessment should be made to ensure that none of the following characteristics are present on the site or in its vicinity which could be of a significant consequence and make a potential although unlikely accident worse:

   a) Site characteristics
      - natural phenomena such as earthquake, seismic sea wave, landslide, subsidence, typhoon, high wave, flood, abnormal cold wave and heavy snow;
      - geological and topographical characteristics such as ground, resistance of ground and fault;
      - climatological conditions such as wind vectors and precipitation;
      - hydrological characteristics of rivers, groundwater, etc.

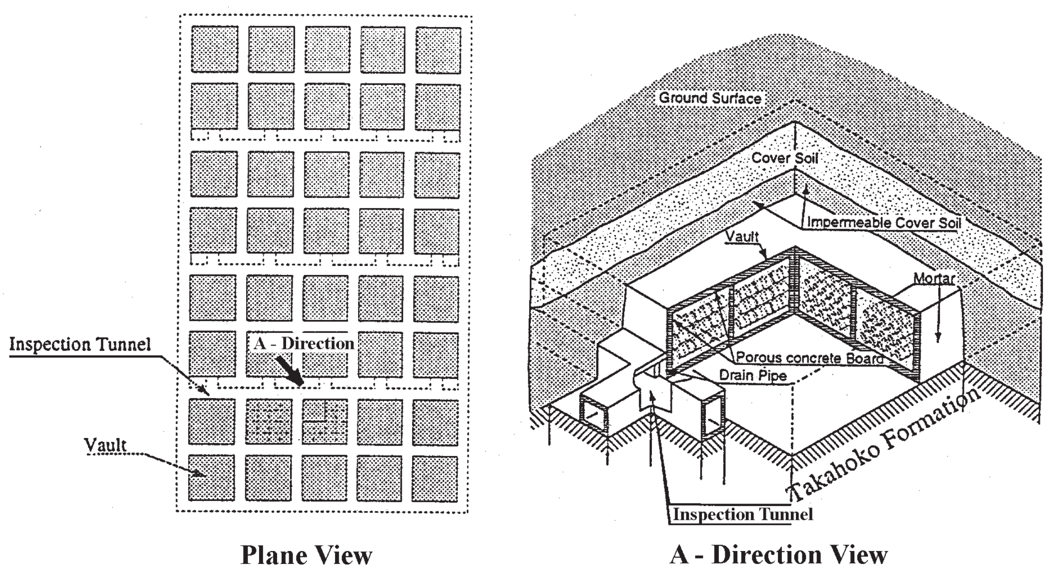
   b) Social environment
      - fire or explosion at nearby plant, etc.;
      - condition of utilisation of river water and groundwater, condition of utilisation of land used for harvest by agricultural products, livestock industry, fish breeding and population distribution;
      - natural resources such as coal and mineral ores.

2. Dose limit

   a) Regulatory dose limit: 1 mSv/y

   b) Safety requirement for LLW disposal:
      - Likely scenario: <10 μ Sv/y.
      - Unlikely scenario: Not significantly exceed 10 μ Sv/y.

Figure A2.6. **Outline of No. 1 burial facility**



Other features

No. 1 disposal facility:

Surface of the repository is 0.048 km^2, corresponding to the area of cells present.
Number of cells is 400 at present and will be 640 in 1998.
Annual number of operating days is 244 days/year.

No. 2 disposal facility:

Number of cells will be 576 until 2010.
Annual number of operating days is 244 days/year.

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COSTS

(million Japanese Yen, JPY)

Planning and licensing		Construction		Operating (per year)		Closure		Miscellaneous[1]	
R&D Site screening Licensing		Design Facilities		Administration Handling Overpacking Filling Backfilling Others Radioactivity monitoring Number of staff				Communication or public relations Economic incentives	
Total	**8 900**	**Total**	**48 100**[2]	**Total**	**N.A.**	**Total**	**N.A.**	**Total**	**7 800**

Operating costs during institutional control of the repository	
Total	N.A.

Exchange rate as of 1 July 1995
84.6 JPY = 1 US$

Disposal facility	No. 1	No. 2
Capacity of the repository	40 000 m^3	40 000 m^3
Annual rate of waste delivery	5 000 m^3	5 000 m^3

Notes:

The cost data include both No. 1 and No. 2 disposal facilities. The cost data are expressed in yens of January 1997. Given that the domestic wholesale price index (DWPI, from the monthly report on Wholesale Price Indexes of Research and Statistics Department, Bank of Japan) was almost the same in 1997 as in 1995, – DWPI in July 1995 is 96.1 and DWPI in January 1997 is 95.2 – the cost data in January 1997 yen was assumed to be equal to the cost data in 1 July 1995 yen.

1. Land, road, etc.
2. Financial charges are not included.

KOREA

General

In 1996 the government amended its policy on the national radioactive waste management programme so that KEPCO (Korea Electric Power Corporation), the national electric utility in Korea and main producer of the radioactive waste shall work on the practical aspect of radwaste management such as siting, designing, construction and operation of the radioactive waste and spent fuel management facilities, as well as management of waste from medical care, industry and research.

The planned repository was a rock-cavern type with a capacity of 20 000 m^3 of conditioned low-level short-lived waste. The design was based on the concept of natural and engineered barriers. The repository was designed to stock radioactive materials until they decayed to a harmless level.

The repository consists of five rock caverns of three different designs, depending on the type of waste to be disposed of and how it is packaged. Three rock caverns are of the same type and they are 140 metres long, 19.1 metres wide and 21 metres high, resulting in a net capacity of nearly 50 600 normalised packages (200-litre drums), stored in six tiers. This volume results from an optimisation process.

At present 48 000 drums of LLW are stored at reactor sites; 380 m^3 (or the equivalent of 1 900 drums) of LLW from other sources (fuel manufacturing, research and radioisotope users) are stored in a designated facility in Taejon. Other sources are fuel manufacturing, research and radioisotope users.

Several measures are being taken by KEPCO to increase storage capacities for radioactive waste. KEPCO has reduced the volume of radioactive waste generated from nuclear power plants by 60 per cent, that is from 120 m^3 per reactor-year in the early 1990s to 50 m^3 per reactor-year in 1995.

Estimated total amount of LLW from nuclear power plants may reach 52 000 drums by the year 2000, 100 000 drums by the year 2010, and 170 000 drums by the year 2020. However, with an aim of further reducing the waste volume and enhancing quality of radioactive waste form, a R&D programme has been initiated to develop a so-called low-level waste vitrification technology. When the result of this research becomes commercialised, operational waste production will be around 10 m^3 per reactor-year which will, without doubt, contribute to the safe storage of radioactive waste.

With respect to radiation protection and safety standards in Korea, radioactive waste is managed in compliance with the Atomic Energy Law. Radioactive waste is classified into two categories, depending on the surface dose rate of the solid waste:

Low Level Waste (LLW) : Solid waste whose surface dose rate is lower than 2 000 mR/h;

High Level Waste (HLW): Solid waste whose surface dose rate is 2 000 mR/h or beyond;

Very Low Level Waste(VLLW): Radioactivity is lower than 100 Bq/g for radionuclides whose half-life is shorter than 100 days.

Disposal of LLW is specially managed in accordance with the several governmental notices on design base, site criteria, acceptance conditions and performance objectives of the repository.

Nuclear power generation

Data as of July 1995 are as follows:

Total net nuclear capacity	8.6 GWe
Number of nuclear units	10
Nuclear electricity generated in 1995	65 TWh
Cumulated net nuclear electricity generation (1977-1995)	558.6 TWh

Information on the repository

Name and location

No site has yet been selected.

Status

The site of the repository has not yet been selected.

Until the repository is available, KEPCO will store radioactive wastes in nuclear plant sites. Interim storage facilities in the nuclear power plants can store LLWs until 2010 or beyond.

Time schedule

Because the new radioactive waste management programme including site selection and disposal scheme will be formulated in 1998, fixed-time schedule is not available at present.

Operator

The repository will be operated by KEPCO. The Korea Atomic Energy Research Institute (KAERI) had been responsible for operation of the repository before the turnover of radioactive waste management to KEPCO in December 1996.

Type

The conceptual design was a rock-cavern type. Retrieval is not required. Radioactive waste is contained in 200-litre drums which are stacked in six tiers.

Geological formation

The site has not yet been specified. The conceptual design is based on granite.

Types, origins and amounts of radioactive waste

Types : only LLW will be accepted in the repository.

Radiation limit : 2 000 mR/h or below, at the surface of the solid waste.

Form of packaging : 200-litre steel drums or concrete containers.

Inventory of LLW for disposal at the repository

Origin	Amount (m^3)	Total Radioactivity (Bq)
Electricity sector	20 000	5.76×10^{15}
Research facility		N.A.
Radioisotopes • production • medical uses		N.A. N.A. N.A.
Historical		N.A.
TOTAL	20 000	5.76×10^{15}

Reception capacity

- Daily reception capacity will be about 8 m^3 (40 drums).
- Annual number of operating days: 250.
- Reception capacity will be 2 000 m^3 (10 000 drums) per year.

Other features

- Length of the storage cavern: 700 metres.
- Total volume of the cavern: 1.74×10^5 m^3.
- Operation will be interrupted by severe weather conditions and maintenance.

- Anticipated events for safety evaluation are intrusion, earthquake, waterflood and airplane crash.
- Disposal of LLW is specially managed in accordance with several governmental notices on design base, site criterion, acceptance condition and performance objective of the repository.
- Site criterion defines earthquake, waterflood and airplane crash.

The following are specified in Government Notice No. 94.2, "Performance objective criteria":

Individual risk

The predicted radiological risk to any individual in a critical group, that is assumed to be present at a time and place where the danger from LILW disposal is likely to be the highest, shall not exceed 10^{-6} fatal cancer and serious genetic risk per year.

Time scale of performance assessment

The period demonstrating compliance with the individual risk requirements need not exceed 1 000 years. When the predicted risk does not peak in 1 000 years, there must be reasonable arguments that beyond 1 000 years, the rate of radionuclide release into the environment will not suddenly and dramatically increase and that acute radiological risks will not be encountered by future individuals.

Estimate of individual risk

The calculation of individual risks shall be made either by annual individual effective dose calculated as the output from deterministic pathway analysis, or by arithmetic mean value of annual individual effective dose from the distribution of individual effective doses in a year, calculated as the output from probabilistic analysis. The risk conversion factor of 5.0×10^{-2} per Sievert is recommended.

COSTS[1]

(million Korean Wons, KRW)

Planning and licensing		Construction		Operating (per year)	Closure	Miscellaneous	
		Design	4 100	Not available	Not available	Communication or public relations	N.A.
		Extension Facilities[2]	62 000			Economic incentives[4]	175 000
						Sealing of site	N.A.
Total	**N.A.**	**Total**	**66 100**[3]	**Total**		**Total**	**175 000**[5]

Operating costs during institutional control of the repository
Not available

Exchange rate as of 1 July 1995

762 KRW = 1 US$

Notes:

1. All costs are given in real terms, i.e. undiscounted costs expressed in national currency unit (KRW) as of July 1995, and past costs are inflated using national inflation indicators unless otherwise provided.
2. Including service building, other electric and mechanical equipment, labour, lifts in the shafts, waste handling, ventilation, service, control, maintenance and drainage areas.
3. Or 3.30 KRW/m^3.
4. Such as local community development aids.
5. The costs are given for 37 years. Cost per m^3 is 8.75 KRW.

SPAIN

General

Radioactive waste generation began in Spain during the 1950s in association with the first applications of radioactive isotopes in industry, medicine and research. Spain's first nuclear power plant began its operation at the end of 1968. At present there are some one thousand installations that possess the administrative authorisation required to use radioactive isotopes (small producers), nine nuclear groups (7 GWe net) and a tenth is now entering the dismantling phase. There are also activities and installations pertaining to the front end of the nuclear fuel cycle (mining, milling and the manufacturing of fuel elements).

Until 1985, the research centre, Junta de Energía Nuclear (now CIEMAT) provided radioactive waste removal, and subsequent conditioning and temporary storage services to the small producers. Since the beginning of their operation, the nuclear power plants and fuel cycle facilities have had the capacity to condition and temporarily store their own radioactive wastes.

ENRESA (Empresa Nacional de Residuos Radiactivos, S.A.) began its operations in the second half of 1985. It is a state-owned company created by the Government, in accordance with a previous parliamentary resolution, by a Royal Decree of 4 July 1984. ENRESA is responsible, among other duties, for the design, construction, operation and closure of LLW disposal facilities.

With a view to ensuring the disposal of LLW in Spain, ENRESA has been operating El Cabril centre since 1992. The repository is based on a system of shallow ground disposal with engineered barriers. The facility is basically made up of the following buildings and structures:

- conditioning building which houses the necessary treatment and conditioning systems (compacting, incineration, immobilisation, etc.);
- disposal structures which consist of reinforced concrete cells (vaults) aligned in two layers;
- quality verification laboratory which tests and controls the characteristics of radioactive waste packages received or conditioned at the facility and carries out research activities; and
- services and control building such as container manufacturing, waste transitory storage, industrial safety, reception, technical services, general services, maintenance workshop, and administration.

Nuclear Power Generation

Data regarding nuclear power generation as of 1 July 1995 are as follows:

Total nuclear capacity	7.2 GWe
Number of nuclear units	9
Nuclear electricity generated in 1996	54.1 TWh
Cumulated nuclear electricity generation (1969-1995)	630.7 TWh

Information on the repository

General

The El Cabril repository is located in the municipality of Hornachuelos, situated in the north of the province of Córdoba, some 400 km south-west of Madrid.

The construction period was between January 1990 and July 1992. The operational licence was granted in October 1992. The date of closure has not yet been decided; the institutional control period will be 300 years after closure.

The facility occupies a surface area of 20 hectares on a geological formation of gneisses and mica schists more than 300 metres thick.

Type

The repository is a shallow-land type with engineered barriers.

The waste packages, most of which are 220-litre steel drums, are placed inside reinforced concrete containers (external dimensions 2.25 x 2.25 x 2.20 metres) and the drums are immobilised inside the container forming a block weighing some 24 metric tons. Each container is capable of holding eighteen 220-litre drums.

These containers are placed, in contact with each other, into the disposal vaults. Each vault has a capacity of 320 containers and the outside dimensions are 24 x 19 x 10 metres, with a central cross or strip left to allow for container manufacturing and positioning tolerances.

The disposal zone consists of two areas or platforms; the northern area has 16 vaults and the southern has 12 vaults. The platforms are horizontal surfaces some 90 metres wide, excavated in trenches in the hillside. The vaults are half-buried with regard to the operating level and are laid out in two rows served by a sliding roof that moves along rails. The roof carries a 32 metric ton travelling crane for handling the containers, operated by remote control to minimise doses in operation.

Each vault is linked by the bottom plate to a network of pipes to collect any seepage water. Once a disposal vault has been fully loaded, the central strip is filled with gravel and an upper reinforced concrete closing slab is built. Finally, it is waterproofed with a synthetic covering.

When all the vaults of a platform are closed, the area will be topped with a low permeability cover, formed by alternating layers of waterproof and draining material.

Types, origins and amounts of radioactive waste

Types and origins: Electricity sector, mainly 220-litre drums, others are metallic drums of different volume (180, 290, 400 and 480 litres). Small producers, 220-litre drums, 25-litre bags, 25-litre liquid containers and sealed sources of different sizes; these wastes are treated (compacted, incinerated or immobilised in 220-litre drums) prior to conditioning in the concrete container.

Remote handling is used in most transfer, treatment and conditioning operations. Compactable wastes follow an independent line.

Inventory: Electricity sector, 95 per cent; small producers, 5 per cent.

Reception capacity

The designed reception capacity of the facility is 660 containers per year. At the moment, the annual volume of ready for disposal is 440 containers, equivalent to 5 000 m^3.

Other features

At the end of 1997, some 2 000 concrete containers were disposed of and six vaults were closed. The capacity of the facility could be enlarged, if required, by the construction of new vaults.

Safety requirements

The long-term radiological acceptance criteria defined by the Spanish Nuclear Safety Council is a risk limit of 10^{-6} per year or the equivalent dose associated with this risk level (0.1 mSv/year). The safety analysis performed show that the former criteria is complied with for credible yet conservative scenarios, taking into account the dose limit.

Two different studies of human intrusion scenarios have been performed. In the first one, following the French Safety Rule RFS I.2, it is assumed that a human intrusion in the repository occurs deterministically 300 years after the closure (i.e. just after the end of the institutional control period) in the form of an extensive public work or the settlement of a dwelling in the area occupied by the wastes. The second one assumed a residential scenario defined and evaluated following the recommendations from the OECD/NEA and considering the environmental impact statement of US 10 CFR 61.

Cost

Aggregated Cost of LLW Repository

Unlike other parts of this report, costs in this section are expressed in discounted terms.

The discounting technique is used to obtain a parameter that takes into account the aggregated cost, the volume of waste involved and both time shares.

The approach considered is that the costs of the repository are recovered, when the wastes are disposed of, through incomes proportional to the volume of waste. In this case the equilibrium equation is that the levelised value of the aggregated cost flow (C) should be equal to the levelised value of income flow (I). Because income = unit cost (p) x volume and p is supposed to be constant, I = p x V, where V is the levelised value of volume flow. Therefore the unit cost can be calculated as p = C / V.

Taking into account a discounting rate of 3.5 per cent the resulting unit cost is 0.55 MPT95 per m^3 as disposed (MPT95 = million Spanish pesetas of 1995).

This figure can be broken down as follows :

	MPT95/m^3	**Percentage**
Planning & licensing	0.042	8
Disposal	0.110	20
Services & administration	0.273	50
Others [1)]	0.123	22

1) Long-term cover, institutional control, social communications, local community aids.

COSTS

(million Spanish Pesetas, ESP)

Planning and licensing		**Construction**		**Operating** (per year)		**Closure**		**Miscellaneous**	
R&D	1 600	Design	360	Administration	170	Long-term		Communication or	
Site screening	120	Disposal		Handling and		cover	700	public relations	80/year
Sub-total	**1 720**	vaults (28)[1]	4 750	Overpacking[4]	30			Economic incentives[7]	
Licensing	950	Buildings[2]	2 650	Filling[5]	60				
		Facilities[3]	4 940	Others[6]	500				
				Radioactivity					
				monitoring	150				
				Number of staff	70				
Total	**2 670**	**Total**	**12 700**	**Total**	**910**	**Total**	**700**	**Total**	**8 000**

Operating costs during institutional control of the repository[8]	100/year

Capacity of the repository	100 000 m^3
Annual rate of waste delivery	5 000 m^3

Exchange rate as of 1 July 1995

121.37 ESP = 1 US$

Notes:

All costs are given in real terms of 1995 value (MPT95), i.e. undiscounted, past cost inflated using national inflation indicators.

1. The construction cost for additional vaults would be 170 million pesetas/vault including excavation and infrastructure.
2. Containers manufacturing building (350MPT), Conditioning building (1 000MPT) and Services and administration buildings (2 650MPT).
3. Facilities exclude treatment and overpacking facilities (incineration, compaction and packaging into drums).
4. Overpacking cost is not included.
5. Filling costs include the upper reinforced concrete closing slab that is built once a vault has been fully loaded; the cost for one vault is 44 MPT95, so the figure presented in the operating cost is derived from the annual rate (44 x 440/320 = 60MPT95).
6. Utilities, services, physical protection, etc.
7. The economic incentives for local community are based on a fixed term of 103 MPT95/year and a variable term of 0.11 MPT95/m^3 as delivered. The total amount for the operational period rises to some 6 400 MPT95.
8. The annual cost is estimated at some 100 MPT95/year. The total cost for this concept is 5 000 MPT95 at the beginning of the period; this figure is the net present value of the annual expenditures (100 MPT95 over 300 years) and includes a discount rate of 2 per cent.

SWEDEN

General

According to Swedish law, the responsibility for the safe handling and disposal of radioactive waste lies with the waste producers, i.e. the nuclear power utilities and the Studsvik research centre. The utilities have assigned to SKB the duty of leading and co-ordinating the work that has to be done in order to fulfil this responsibility. This means that SKB is responsible for the necessary facilities and their safety.

SFR, the Swedish Final Repository for Radioactive Waste (Figure A2.7), has been designed for LLW/ILW (Low-Level Waste/Intermediate-Level Waste) from the operation and maintenance of all Swedish nuclear power plants. The repository also accepts waste from research, medicine and industry, providing the wastes have similar properties and radionuclide contents as the waste from the power plants.

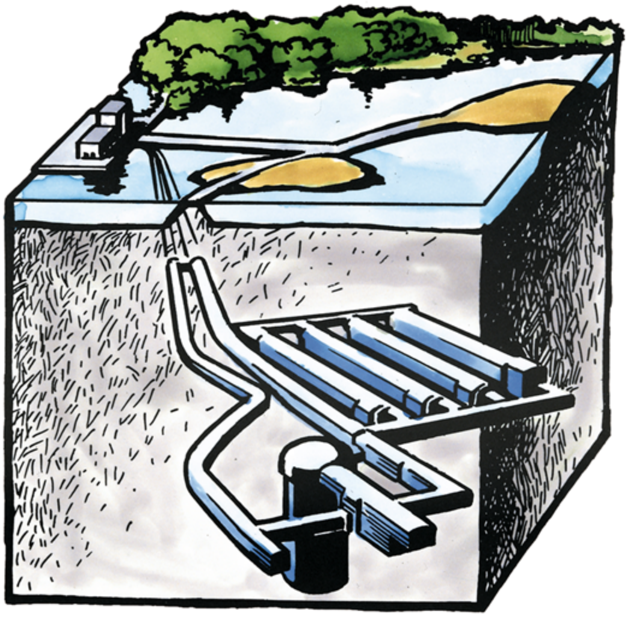
The repository has been in operation since 1988 and has a capacity of 63 000 m^3 of waste, including packagings. The license for SFR allows for 90 000 m^3 of waste. With an operational period of 40 years for the nuclear power plants, a capacity of 63 000 m^3 is sufficient. Until today SFR has received approximately 20 000 m^3 waste. It is located close to the nuclear power plant at Forsmark, in a crystalline bedrock, 60 metres below the bottom of the Baltic sea. The entrance is at Forsmark harbour and two tunnels lead to the disposal area, 1 km from the shore. SFR consists of an above ground section and an underground section. The above ground section consists of an office, a workshop, a terminal building for transport containers and a ventilation building.

The post-closure safety of the repository has been analysed as part of the licensing procedure. The safety analyses are updated every 10 years and a full assessment of the post-closure safety has to be performed before sealing of the repository.

SFR has five different rock chambers with different barrier systems. The most active waste is deposited in a 50-metre high concrete silo, surrounded by a clay buffer. The silo will contain almost 90 per cent of the total activity of SFR, which has been estimated at 10^{16} Bq for the year 2010. The remaining 10 per cent of radioactivity will be disposed of in four more simple rock caverns. These four caverns are 160 metres each in length. The cross section depends on the type and size of waste packages to be disposed of in the cavern. The width varies from 15 to 20 metres and the height from 10 to 17 metres.

The location ensures a very small hydraulic gradient and therefore the groundwater is almost stagnant. The location also ensures that no one will drill for drinking water in the area at least for a period of about 500 years. After that, the land uplift will raise the shallowest sea bed formation above sea level. The repository is designed to contain the radionuclides until they decay to an insignificant level in the repository or that, if released, the rate will be so low that concentration in the biosphere will be insignificant. The design objective has been to achieve isolation/retention so that the calculated dose to any individual is well below 0.1 mSv/year at all times. Collective dose from the repository shall not significantly contribute to the total collective dose from the nuclear fuel cycle.

Figure A2.7 **SFR, Final repository for radioactive waste.**



Nuclear power generation

Data regarding nuclear power generation as of 1 July 1995 are as follows:

Total net nuclear capacity	10 GWe
Number of nuclear units	7
Nuclear electricity generated in 1995	66.7 TWh
Cumulated nuclear electricity generation (1972-1995)	991.2 TWh

Information of the repository

Name and location of the repository

SFR, final repository for radioactive operational waste. Located close to the Forsmark nuclear power plant, 150 km north of Stockholm.

Status

The repository has been in operation since 1988.

Time schedule

Time schedule of the repository is as follows:

Beginning of construction	07/1983
Completion of construction	03/1988
Opening of the site	04/1988
Date of closure	Not yet decided*
Period of institutional control	Not necessary

* An extension for decommissioning waste is foreseen.

Operator

The repository is operated by SKB, owned by the Swedish Nuclear Power utilities.

Type

The repository consists of 1 silo and 4 caverns. Retrievability is not required. The waste is contained in packages of different sizes. In the silo, the waste packages will be backfilled with a special permeable grout. The cavern for intermediate-level waste is divided into 13 cells. Once a cell has been filled up with waste packages, a concrete lid will be put on top of the cell.

Geological formation

The repository is located in crystalline bedrock, 60 metres below the bottom of the Baltic sea.

Types, origins and amount of radioactive waste

Types: VLLW, LLW and ILW are accepted in the repository and treated separately.

Radiation limit: the surface dose rate is 2 to 500 mSv/h, depending on the type of cavern.

Five different types of packagings are used: 200-litre drums, cubical concrete or steel boxes with a side length of 1.2 metres and concrete tanks with a volume of 10 m^3 and ISO containers.

Table 1. **Inventory of LLW disposed of at the repository, as of 1 July 1995**

Origin	Amount (m^3)	Amount (t)	Emission type	Total radioactivity (Bq)
Electricity sector	16 383		β,γ	3×10^{14}
Research facility	580		β,γ	6×10^{10}
TOTAL	16 963		β,γ	3×10^{14}

Reception capacity

The daily reception capacity of waste is 30 m^3 and the final reception capacity will be 63 000 m^3.

Other features

Each of the four caverns is 160 metres long. The silo is 50 metres high and has a diameter of 25 metres.

The repository is closed four months a year (May to August).

The waste is transported to the site by ship. When the icelayer is thick, the ship sometimes has problems reaching SFR, but during normal winters this poses no problem.

Safety requirements

Anticipated events for operational safety evaluation are fire and handling accidents, for instance. Those for post closure safety evaluation are intrusion, earthquake and waterflood.

COSTS

(million Swedish Kronors, SEK)

Planning and licensing		**Construction**		**Operating** (per year)		**Closure**		**Miscellaneous**	
R&D	62	Design and management	243	Administration	4.0		100	Communication or public relations	0.06/year
Site screening	5			Handling	6.5				
Sub-total	**67**	Vaults and tunnels	287	Filling	3.0				
Licensing	19	Concrete trenches, silos, etc.	221	Others[3]	11.5				
		Surface facilities[1]	120	Number of staff	15[4]				
		Underground facilities[2]	317						
Total	**86**	**Total**	**1 188**	**Total**	**25.0**	**Total**	**100**	**Total**	

Capacity of the repository	63 000 m^3
Annual rate of waste delivery	2 500 m^3

Exchange rate as of 1 July 1995

7.269 SEK = 1 US$

Notes:

1. Terminal, administration and ventilation buildings, as well as workshop.
2. Control room and mechanical equipment.
3. Maintenance and electricity.
4. Services such as security and part of administration are purchased from Forsmark power plant.

SWITZERLAND

General

According to Swiss law, the safe handling and disposal of radioactive waste is the responsibility of the waste producers. The operators of nuclear power plants (NPPs) and the Federal Government which is responsible for waste arising from medical, industry and research uses (MIR wastes), have founded Nagra, the National Co-operative for the Disposal of Radioactive Waste. Nagra is responsible for the disposal of all categories of radioactive waste and for the research and development work associated therewith.

The Swiss waste management strategy foresees two types of repositories for categories of waste which differ in terms of intensity and decay times of the radiation they emit:

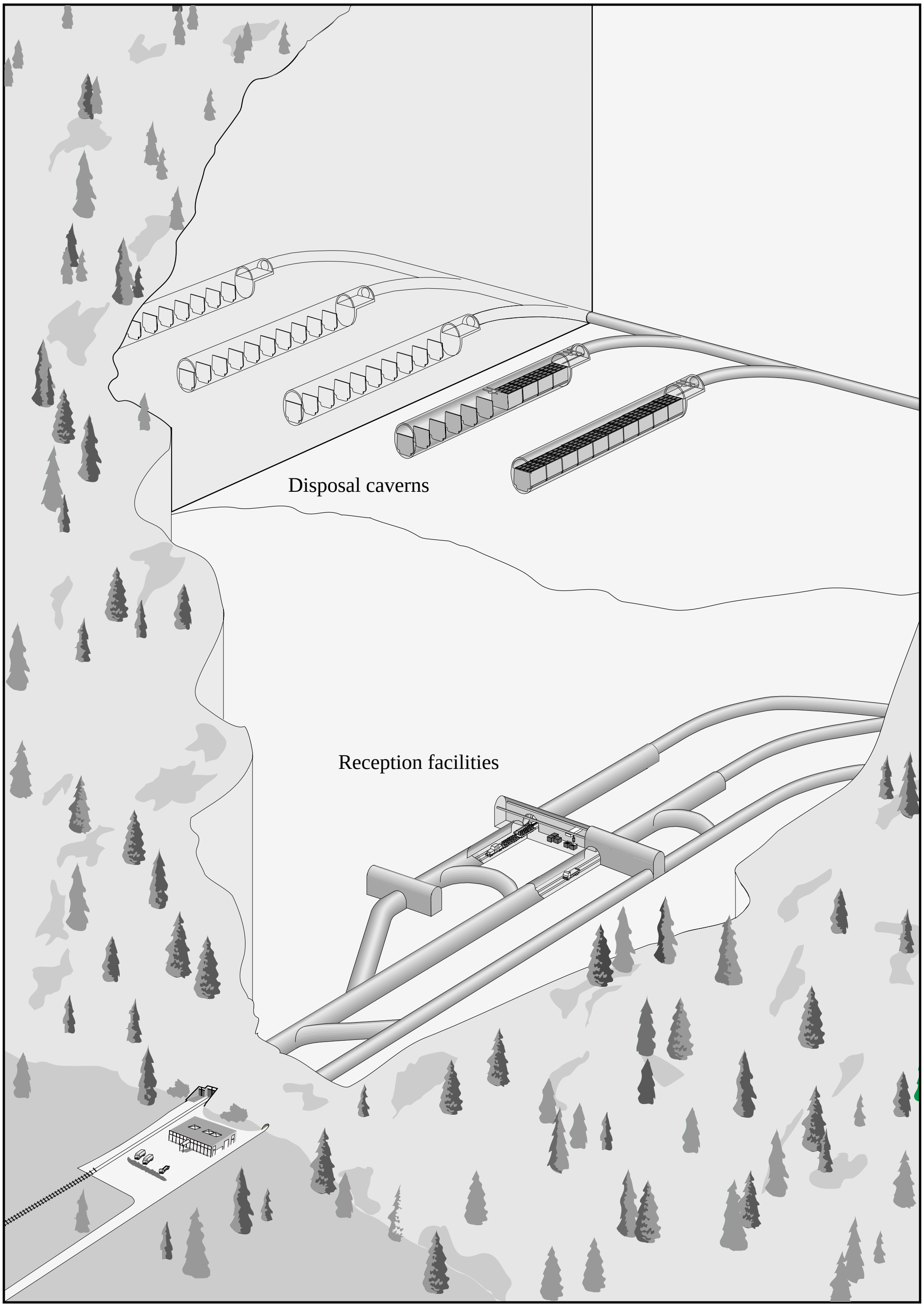
- Low and intermediate-level waste (LILW) from the operation of NPPs, reprocessing of spent fuel and decommissioning of nuclear power plants, and MIR waste (Government responsibility).
- High-level waste (HLW) and long-lived intermediate-level waste (TRU) from reprocessing or from the direct disposal of spent fuel elements.

All wastes require interim storage until the relevant repositories become operational. Storage capacity is presently available at the NPP sites, at the (foreign) reprocessing plants and in a facility operated by the Federal Government. Within a few years, a centralised interim storage facility (ZWILAG) will be available in Switzerland at Würenlingen. Interim storage is the responsibility of the NPP operators and the Federal Government (MIR wastes).

A specific LLW repository project has been worked out for a site proposed in central Switzerland (Wellenberg). However, this site is subject to further investigations and licensing. The planned storage capacity of the repository is 200 000 m^3 . It takes into account overpacking of all wastes upon delivery to the repository, except for the 57 000 m^3 of decommissioning waste which are delivered in large concrete containers. Additional capacity is considered for layout purposes only.

The costs presented in this report are those which have been estimated for the scenario assumed by the NPP operators when they reviewed in 1995 their calculations of the financial reserves required for future liabilities. The scenario and associated costs are conservative. The project for the repository and the time schedule for its realisation may be subject to substantial modifications, e.g. as a consequence of the trend towards reduction of waste volumes resulting from ongoing technical advances and optimisation strategies on the part of the waste producers.

Figure 8. **Perspective view of LLW repository (artist's impression)**



Nuclear programme (1995)

The Swiss nuclear power system consists of five reactors (two BWRs and three PWRs) which were brought into operation between 1969 and 1984. For the cost estimates, it was assumed that each reactor would be in operation for a period of 40 years.

Total net nuclear capacity	3.1 GWe
Cumulated nuclear electricity generation (1969-1995)	400.5 TWh
Cumulated nuclear electricity generation over 40 years (assumed lifetime of nuclear power plant)	900 TWh
Gross fuel inventory, tonnes of heavy metal (uranium or mixed uranium/plutonium)	3 056 tHM

Information on the repository

Name and location

The proposed Wellenberg repository site is situated in the community of Wolfenschiessen, approximately 20 km south-southeast of the city of Lucerne, in central Switzerland.

Status

Final disposal is effected inside a mountain, with horizontal access tunnel and an overburden of approximately 500 metres, in horizontally mined, parallel, concrete lined caverns with a cross-sectional area of approximately 160 m^2 and a length of up to 300 metres (Figure A2.8). The total length of the caverns is 1 500 metres, resulting in a total disposal volume of 240 000 m^3.

Time schedule

Cost estimates in this report are based on the 1995 project reference schedule with:

- two construction phases of 6 years each (2001-2006, 2019-2024);
- two operating phases of 12 and 18 years, respectively (2007-2018, 2025-2040); and,
- closure between 2041-2044 (or possibly later, after a surveillance period).

This schedule will, however, be delayed by recent developments and the duration of the operating phases might be reduced.

Operator

Genossenschaft für nukleare Entsorgung Wellenberg (GNW).

Type

Deep repository with multiple barrier system.

Geological formation

The repository lies at 540 metres above sea level, 500 metres below ground level in a large volume of marl host rock with sufficient reserves so that less suitable rock zones can be avoided. Investigations carried out to date from the surface indicate that the rock has very low permeability (unsaturated zones, very old ground-waters) and that the risk of negative geological surprises is minimal thanks to good exploration.

Types, origins and amounts of waste

LILW volumes were assumed as follows, on the basis of full reprocessing and with an average overpacking factor of 3.3 for the first three categories of waste:

Operational waste from nuclear power plants	40 000 m^3
Reprocessing waste	80 000 m^3
Medicine, industry and research waste (MIR)	23 000 m^3
Waste from decommissioning of nuclear power plants	43 000 m^3
Waste from decommissioning of MIR facilities	14 000 m^3
TOTAL	**200 000 m^3**

Reception capacity

A minimum of 60 m^3 per day.

Other features

The assumption of complete reprocessing is very conservative in terms of disposal cost estimation; if a significant proportion of spent fuel were to undergo direct disposal, the volumes of LILW (and TRU in the HLW/ILW repository) would be considerably reduced.

It was assumed that the repository would be operated 200 days per year. The operational procedures will be as follows:

- reception of waste from truck or railway;
- packaging into concrete disposal containers, filling of voids with special concrete mortar (except for decommissioning waste);
- transport to and placing (by crane) into storage caverns;
- filling of gaps/voids in caverns with concrete mortar (possibly only after an interim surveillance phase during which retrievability of waste may have to be ensured);
- sealing of caverns;
- closing of repository by backfilling all underground spaces and sealing of access tunnels with bentonite plugs.

Safety requirements

Safety can be reliably demonstrated for the Wellenberg site in accordance with the protection objectives mentioned in Chapter 2 of this study. Since not only the storage caverns but also the waste acceptance facilities are underground, most external events (e.g. airplane crash) can be ruled out. Safety evaluation for the post-closure phase included nuclide release by flowing of groundwater, release of volatile nuclides in gas-phase, erosion (including effects from glaciation) and human intrusion.

Results of cost estimates

The total costs of the LILW repository are estimated at around 1.9 billion Swiss Francs (CHF, price in 1995). Detailed figures for the four main components are as follows:

- **Preparatory work (400 million CHF):** all preparatory work in connection with disposal of LILW from the founding of Nagra in 1972 up to the beginning of construction; this includes site characterisation using an exploratory drift.
- **Construction (820 million CHF):** site accessing, construction and equipment of facility in two six yearly stages.
- **Operation (610 million CHF):** operation in two phases of twelve and sixteen years respectively which includes delivery of concrete disposal containers (except for decommissioning waste), filling, emplacement in the caverns and filling of voids as well as maintenance and replacement of capital assets.
- **Closure (70 million CHF):** all dismantling and demolition work, backfilling and sealing of access tunnels and waste handling caverns including recultivation of the site.

General outgoings (concession charges and compensation payments) of an average of approximately 7.5 million CHF per year as well as expenditure on Nagra project work and reimbursement of regulatory authority costs are contained in the construction and operating columns.

UNITED KINGDOM

General

In the United Kingdom, Low Level Wastes (LLW) are defined as those wastes whose radioactive content does not exceed 4 GBq/t alpha or 12 GBq/t beta-gamma. With the exception of a disposal facility associated with the operation of the Dounreay Fast Reactor Research site, on the north coast of Scotland, essentially all LLW in the UK is disposed of at the Drigg site, near Sellafield, in West Cumbria.

UK policy on LLW disposal is set out in "Review of Radioactive Waste Management Policy: Final Conclusions", Command 2919, issued in July 1995. The policy fully reflects the principles set out in IAEA's fundamentals document "The Principles of Radioactive Waste Management" and associated Safety Standard "Establishing a National System for Radioactive Waste Management".

The radiological protection principles underpinning Government Policy take account of advice provided in ICRP 60. With the exception of the new concepts of dose and risk constraint, the recommendations of the ICRP already formed the basis of radiological protection in the UK. ICRP 60 also recommended changes in the methodology used to calculate doses. Although these will not be formally implemented until negotiation of the revised Euratom Basic Safety Standards Directive is complete and becomes European Law, the new methodology has already been used for the authorisation of discharges under the Radioactive Substances Act 1993.

Disposals of radioactive waste in the UK are governed by the Radioactive Substances Act (RSA 1993) and controlled through authorisations issued by the Environment Agency. Authorisations are required by the disposal site operator and separately by each waste generator. Where new radioactive waste disposal facilities are to be introduced then the limits and conditions of authorisation under RSA 1993 will be based on the principles and requirements set out in "Disposal Facilities on Land for Low and Intermediate-Level Radioactive Wastes: Guidance on Requirements for Authorisation" issued in 1997 by the Environment Agency, the Scottish Environment Protection Agency and the Department of the Environment in Northern Ireland. The general principles contained in this document will also be used in reviewing the authorisations for future disposals to existing LLW disposal sites.

The limits and conditions indicated above are underpinned by a comprehensive set of acceptance criteria for waste received at Drigg, an environmental monitoring programme and a technical programme, the latter including a long-term safety case assessment.

The Drigg site is also classed as a Nuclear Licensed Site as defined by the Nuclear Installations Act 1965 and as such is subject to regulation by Her Majesty's Nuclear Installations Inspectorate.

Nuclear Power Generation

Data regarding nuclear power generation as of 1 July 1995 are as follows:

Total net nuclear capacity	12.9 GWe
Number of nuclear units	35
Nuclear electricity generated in 1995	80.6 TWh
Cumulated nuclear electricity generation (1956-1995)	1 313 TWh

Information on the repository

Name and location

Drigg: 20 km south of Whitehaven, West Cumbria.

Status

The site has been in operation since 1959. Until 1988, disposals were solely in trenches approximately 25 metres wide, 5-8 metres deep and up to 750 metres long, cut into the glacial tills underlying the site. In 1988, an engineered concrete vault was brought into operation and is currently in use.

Time schedule

Time schedule of the repository is as follows:

Date of first disposal:	Trench 1959; Vault 1988
Closing date:	Trenches 1995; Vaults ~2050
Date of end of institutional control:	Approximately 2170

Operator

The repository is owned and operated by British Nuclear Fuels plc, a state-owned company.

Type

The repository is a shallow-land type. Engineered vaults are located just below ground level. Retrievability is not required.

Geological information

The site consists of glacial deposits of sand, gravel and clay overlying sandstone. Disposal facilities are underlain by clay (engineered where necessary). The vaults/trenches are situated some

10 metres above regional groundwater. There is localised perched groundwater present at repository depth.

Types, origins and amounts of radioactive waste

The repository accepts only solid LLW, as defined above (General). Wastes must be high force compacted (or be uncompactable) and grouted within specially designed 20 m^3 steel containers which are emplaced in the vault using fork lift trucks. Acceptance of other waste forms is subject to special agreement.

Wastes are received from nuclear power plants, nuclear fuel cycle operations, Ministry of Defence, radio-pharmaceutical and radio-isotope production, research, hospitals and other miscellaneous sources.

Reception capacity

The reception capacity of the site is essentially determined by the capacity of the grouting plant, since virtually all containers of wastes received are grouted on site before disposal. The plant can accommodate 80 m^3 per day. The current disposal rate averages some 50 m^3 per day.

Other features

Surface of the repository	36 hectares
Number of trenches filled	7
Number of vaults at present	1
Number of future vaults	12

Rainwater is routed to a local stream which flows into the Ravenglass estuary. When it enters the vault, it is routed as leachate which in turn is routed to holding tanks, proportionally sampled and pumped to sea via a pipeline, as required.

Safety requirements

The safety requirements for radioactive waste repositories are set out in the guidance on requirements for authorisation issued by the Environment Agency *et al* as discussed above (General). The key events for safety evaluation are human intrusion, glacier disturbance, groundwater and gaseous pathways.

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