NUCLEAR ENERGY AND INFORMATION

RADIOACTIVE WASTE MANAGEMENT IN PERSPECTIVE

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

— to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
— to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
— to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium,Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973) and Mexico (18th May 1994). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of the OEEC European Nuclear Energy Agency. It received its present designation on 20th April 1972, when Japan became its first non-European full Member. NEA membership today consists of all European Member countries of OECD as well as Australia, Canada, Japan, Republic of Korea, Mexico and theUnited States. The Commission of the European Communities takes part in the work of the Agency.

The primary objective of NEA is to promote co-operation among the governments of its participating countries in furthering the development of nuclear power as a safe, environmentally acceptable and economic energy source.

This is achieved by:

— *encouraging harmonization of national regulatory policies and practices, with particular reference to the safety of nuclear installations, protection of man against ionising radiation and preservation of the environment, radioactive waste management, and nuclear third party liability and insurance;*
— *assessing the contribution of nuclear power to the overall energy supply by keeping under review the technical and economic aspects of nuclear power growth and forecasting demand and supply for the different phases of the nuclear fuel cycle;*
— *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, 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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LE POINT SUR LA GESTION DES DÉCHETS RADIOACTIFS

Cover: Model of the repository for low-level and medium-level radioactive waste at Olkiluoto, Finland.
Credit: TVO, Finland.

FOREWORD

Each year, about 300 million tonnes of toxic wastes of all sorts are generated in OECD countries, but only 1% of this is radioactive. Yet, radioactive waste has received more attention and caused more public concern than most other types of potentially hazardous or sometimes equally toxic wastes, and continues to trigger a fair number of scientific, technical, political, financial, social, legal and ethical issues all over the world.

There is still little public awareness of the broad scientific and technical consensus that all categories of radioactive waste can be managed and disposed of in accordance with all regulatory requirements by the careful application of current technologies. Similarly, the fact that many stages of radioactive waste management, including the disposal of some industrial low-level and medium-level waste, have been safely implemented for many years and have become routine procedures, is not widely known.

In the tradition of its well established series of reports on key issues relating to nuclear energy, the NEA aims this report primarily at decision-makers, opinion leaders and interested groups of the public who may wish to have a practical reference on the subject.

The report explains the basic principles and main stages of radioactive waste management, including the two current options of direct disposal and reprocessing of spent fuel, as well as the actual and planned use of underground repositories in deep geological formations. It also addresses issues relating to environmental protection, safety assessments, financing, social issues, public concerns, and international co-operation. Annexes summarise the current radioactive waste management programmes in each of the 15 NEA countries (Belgium, Canada, Finland, France, Germany, Italy, Japan, Korea, Mexico, the Netherlands, Spain, Sweden, Switzerland, the United Kingdom and the United States) where such a programme exists.

The opinions expressed in this report do not necessarily represent the views of any Member country or international organisation. It is published on the responsibility of the Secretary-General of the OECD.

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INTRODUCTION

This report is concerned with the safe management and disposal of the radioactive wastes that are an inevitable by-product of the generation of electricity by nuclear power.

Nuclear power is already making a substantial contribution to meeting the energy needs of many industrialised countries without at the same time posing threats to the environment and the climate by emitting acid gases and heat-trapping greenhouse gases. Nuclear reactors currently provide 17% of the world's electricity, and in 1994 produced more electricity in total than that generated from all sources in 1958. There are no insuperable technical obstacles to a significant further increase in the nuclear contribution. However, nuclear power has become a contentious issue in a number of countries, and while its use in some is continuing to grow, others have decided to limit its contribution to around the current level or to eliminate its use entirely.

One of the key issues that has dominated the nuclear debate in recent years has been the safe management of radioactive wastes, particularly the disposal of long-lived wastes. Radioactive wastes form only a small fraction of the total amount of toxic waste produced within OECD countries, which in turn is only a minute fraction of the 9 billion tonnes of waste that these countries produce each year. Despite these facts, radioactive wastes have caused more public concern than any other type of waste, even though they are neither uniquely toxic nor uniquely long-lived. There is little public awareness of the broad scientific and technical consensus that all categories of radioactive waste can be managed and disposed of safely using currently available techniques, that many stages of waste management, including the disposal of some categories of waste, have been safely implemented for many years, and that deep geological disposal is the best option for the most toxic and long-lived wastes. Thus although solutions to the technical problems of radioactive waste management exist, nuclear industries and governments in many countries are still finding some difficulties in applying these solutions.

The primary objective of the OECD Nuclear Energy Agency is to promote co-operation among the governments of its participating countries in furthering the development of nuclear power as a safe, environmentally acceptable and economic energy source. The attitude of the public towards the activities associated with such development depends largely upon its understanding of the issues at stake and of their implications. The Agency is seeking to assist in this effort through the provision of a series of comprehensive reports on key issues in a form that is readily useful to government and understandable to the interested non-specialist public. This report is one of that series.

The challenges and concerns of modern society

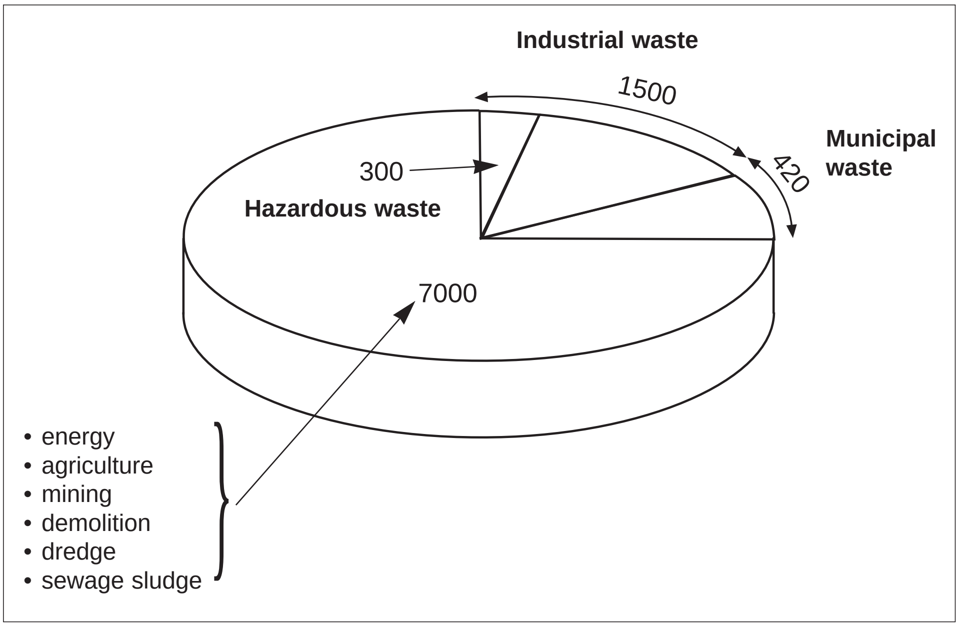
The high standard of living enjoyed by most people in OECD countries depends on a plentiful supply of energy and raw materials, and a complex infrastructure of manufacturing industry and transport. The past few years have been marked by a growing concern that maintaining lifestyles in developed countries and improving those in developing countries, with their ever-increasing populations, will result in more and more environmental damage, some of which may be irreversible.

A major challenge of the coming years is therefore to find ways of reconciling people's aspirations with the need to protect the environment – ways of achieving sustainable development, defined in the *Brundtland Report* of 1987 as development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

A critical objective for policies that are consistent with sustainable development is to change the historic patterns of growth in ways that will result in less per capita energy and raw materials consumption and less waste production, particularly in developed countries. However, global industrialisation and the associated energy and raw materials consumption are bound to increase if the rapidly growing populations of the developing nations are to escape poverty and be given the opportunity to fulfil their aspirations for a better life. Such increases will inevitably result in the production of large quantities of all types of wastes, which will have to be dealt with in ways that do not contaminate the environment or harm people or other living creatures, now or in the future.

The quantity of non-nuclear waste being produced by industrial societies is already vast: 9 billion tonnes of solid wastes a year in OECD countries alone, equivalent to about 10 t per person per year, plus billions of tonnes of liquid and gaseous pollutants, dominated by carbon dioxide. Of the annual total of 9 billion tonnes, 420 million tonnes is municipal waste, 1500 million tonnes, including

Annual production of solid waste in OECD countries
(in million tonnes)



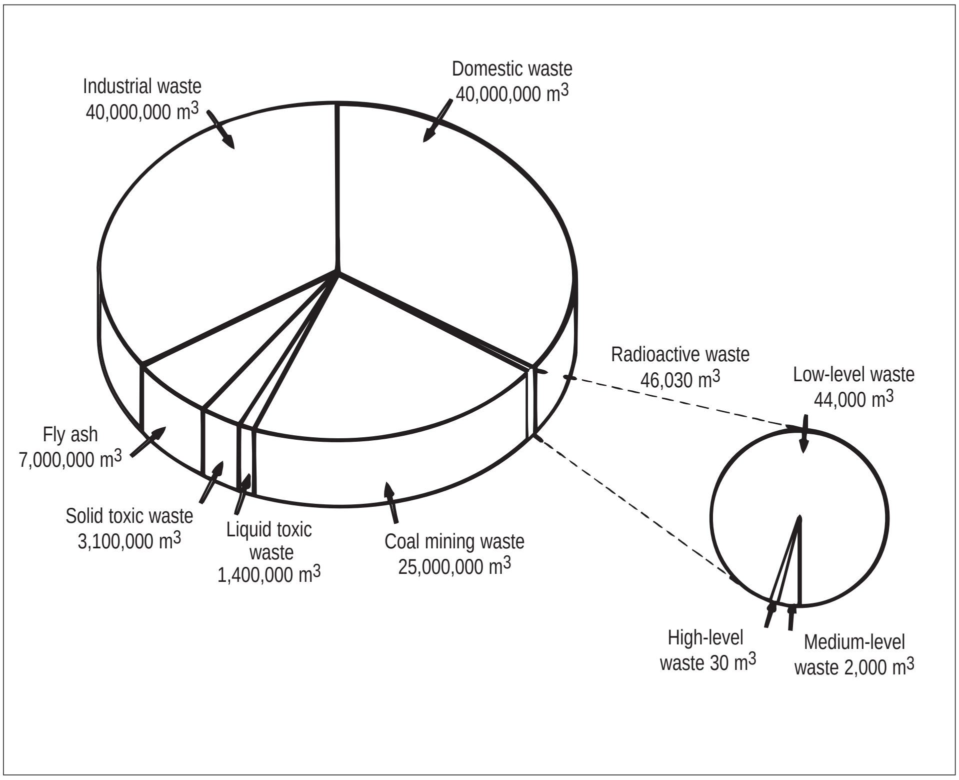
300 million tonnes of hazardous waste, comes from manufacturing industry, and the remaining 7 billion comes from energy production, agriculture, mining, demolition, dredge and sewage products.

Toxic wastes

Modern industrial societies depend on a wide range of manufactured goods, materials, processes and services, many of which result in the production of wastes containing toxic materials such as heavy metals, acids, alkalis, halogenated hydrocarbons, chemical carcinogens, and biologically active substances. One of the most urgent tasks is therefore to develop and implement satisfactory ways of dealing with toxic wastes, usually defined as wastes which are dangerous to human life.

More than 300 million tonnes of toxic wastes are produced in OECD countries each year, and there are a number of well-known examples of past failures to manage these wastes safely. At Love Canal, in New York State, leachate from an abandoned chemical waste disposal site leaked into the basements of houses, causing exposure to benzene, a known carcinogen. The leachate was pumped out of the basements into the Niagara River and Lake Ontario causing

Approximate annual volumes of waste in the United Kingdom



Credit: U.K. Department of the Environment.

contamination, and hundreds of families were evacuated when benzene and chlorinated hydrocarbons were found in the air. Billions of dollars of lawsuits are now going through the courts. The U.S. Environmental Protection Agency has compiled information on 25 000 sites where hazardous wastes were disposed of before regulations were established; 888 of these have been designated as potentially in need of remedial action. There have been many incidents of toxic chemicals being discharged into major rivers, for example the Rhine, and into seas, for example at Miyamata in Japan. Recently, there has been widespread concern about the careless disposal of toxic wastes in Third World countries.

Improvements in manufacturing processes and tighter regulations are helping to reduce the quantities produced, and further improvements are resulting from recycling and better waste treatment methods, but large quantities of toxic wastes will continue to be produced, even if the best available technologies are used.

Radioactive wastes and public concerns

Although only a small fraction of toxic wastes is radioactive, typically less than 1% in a country with a nuclear electricity industry, radioactive wastes have received more attention and caused more public concern than most other types of toxic waste, some of which are equally toxic and long-lived. Concern has been exacerbated by information that has recently become available about the consequences of a number of inadequately planned and controlled past radioactive waste management practices, mainly related to military wastes.

While it is clearly right that there should be a widespread public debate about the disposal of radioactive waste, this debate does not appear to reflect the broad scientific and technical consensus that all categories of radioactive waste can be managed and disposed of in accordance with all regulatory requirements by the careful application of currently available technologies, or the fact that many stages of waste management, including the disposal of some categories of waste, have been safely implemented for many years. In particular, there is broad agreement that deep geological disposal is the best option for the most toxic and long-lived categories of radioactive waste.

The perceived absence of a "solution" to the waste disposal problem is jeopardising the development of the nuclear industry in some countries. Governments and organisations responsible for radioactive waste management are finding some difficulties in gaining acceptance from local communities for the siting of disposal facilities, thereby preventing the disposal of the wastes from past and current nuclear operations, and from medical, industrial and research applications, which have to be safely disposed of regardless of the future of nuclear power.

The role and activities of international organisations

International co-operation is an important element of all national programmes, both for the establishment of strategies and policies and to enable the maximum benefit to be gained from research and development activities worldwide. In addition, there is a growing realisation that many problems of pollution have an international dimension because of the possibility of transboundary and, in some cases, global effects from local emissions.

Many international agencies have a role in the field of radioactive waste management. Some are concerned primarily with the collection, assessment and dissemination of authoritative scientific and technical information, some with the development of regulatory methods and standards, and others with the promotion of bilateral and multilateral agreements and co-operative studies and projects. An important future role will be helping to ameliorate the consequences of past practices and accidents in the former U.S.S.R. and the former Eastern Bloc.

The OECD Nuclear Energy Agency has been particularly active in the area of radioactive waste management, serving as a forum for the exchange of information between specialists, helping to harmonise national legislation and setting up a number of international research projects which have led to important advances in understanding and safety assessment methods for the disposal of long-lived wastes.

Public acceptability of waste management policies and technical and regulatory solutions is a key requirement in all countries. A large proportion of the Agency's work is directed towards assessing and providing unbiased information on the environmental impacts of nuclear power, through its international projects and joint undertakings. The results of these activities are widely published for the benefit of all interested groups including government, industry executives, parliamentarians and other elected representatives at all levels, journalists and academic, research and financial institutions.

Chapter 1

CHARACTERISTICS OF RADIOACTIVE WASTE

Summary

Radioactive wastes derive from a number of sources: medical, industrial, agricultural, and military. While all these sources can in principle cause harm to the environment and to human health, it is the waste produced by the nuclear power industry that causes the most alarm.

Radioactive waste is managed according to the concentration of the radioactivity, the three categories being low, medium and high-level.

Management procedures also depend on the time taken for the radioactivity in the wastes to decay away. While low and medium-level wastes are produced from a variety of sources, high-level waste is produced exclusively from electricity generation and military activities.

The total volume of waste produced by the nuclear industry is minute compared with the volumes produced by fossil-fuel generation. This is because only small amounts of uranium are required to generate large amounts of energy: the complete fissioning of 1 t of uranium would be equivalent to burning 2.7 million tonnes of coal. The high-level wastes are produced in the fuel itself, and the volumes depend on the way in which spent fuel is managed: direct disposal or reprocessing.

Clearly the toxicity of the waste matters as much, if not more, than the absolute volume produced. The toxicity of a substance depends on complex interactions with human tissue: it is therefore difficult to devise a measure that can be applied equally to all types of toxic waste. The toxicity of radioactive materials is generally assessed empirically on the basis of studies such as those of the victims of the Hiroshima and Nagasaki bombings and groups of people that have been exposed to relatively high doses of radiation from medical practices. Additional information comes from studies of populations living in areas of high natural background radiation .

As a result of these studies, the effects of radioactive materials and the radiation they emit on human health are better understood than those of many

other potentially dangerous substances, including many toxic chemical wastes; some of these are potentially as dangerous as radioactive wastes and, unlike them, remain toxic for ever.

The actual hazard presented by radioactive wastes is assessed by considering in detail the effectiveness of every stage of the waste management process and the precise pathways of waste material through the environment and its subsequent uptake by people.

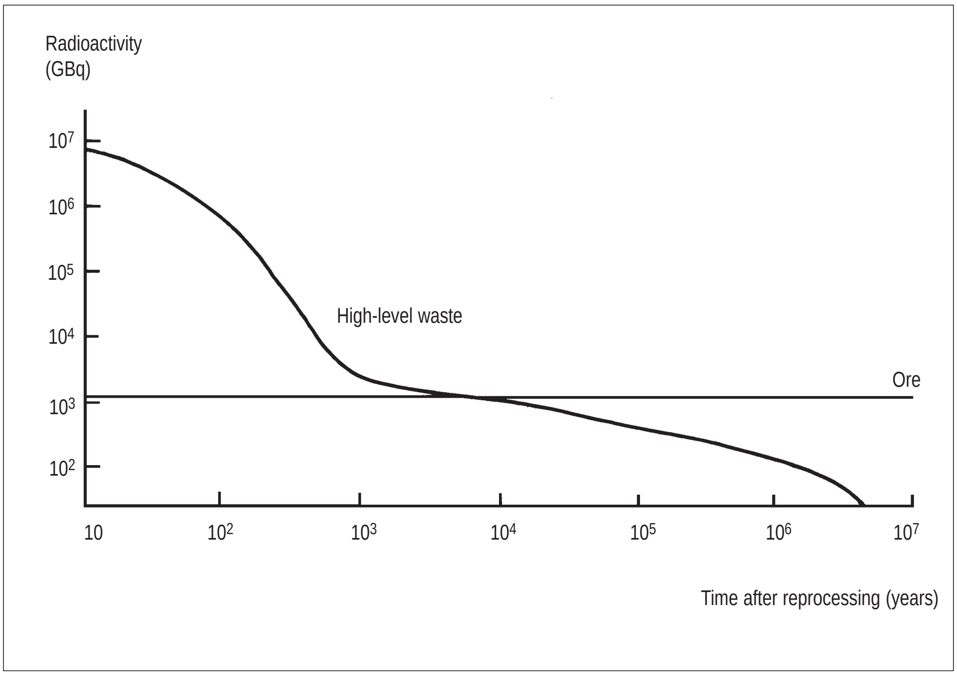
RADIOACTIVE WASTE

The IAEA defines radioactive waste as "any material that contains or is contaminated by radionuclides at concentrations or radioactivity levels greater than the exempted quantities established by the competent authorities and for which no use is foreseen".

Definition, nature and origins of radioactive waste

Most types of waste are, strictly speaking, radioactive, because naturally radioactive materials are found throughout the environment, in the earth, in water and in the air, and inevitably appear in trace quantities in almost all wastes. However, wastes containing very low concentrations of radioactivity are generally deemed to pose no significant hazard to people or to the environment and are therefore of no concern to regulators; they are managed as if they contained no radioactivity whatever. The term "radioactive waste" is reserved for particular classes of waste, defined in national and international regulations, which contain concentrations of radioactive materials above the levels specified in these regulations.

All radioactive wastes emit radiation – that is what is meant by the word "radioactive." The key characteristics that govern the way these wastes are classified and managed are the type and intensity of the radiation they emit, any associated heat production, and the half-lives of the constituents, which govern the rate at which they lose their radioactivity. A half-life is the time taken for the radioactivity of a given quantity of radioactive material to fall by one-half: in two half-lives it falls to a quarter, in 10 to about one-thousandth and in 20 to about one-millionth of the original level. Radioactive wastes can contain natural or "man-made" radioactive materials, or mixtures of the two. They result from nuclear electricity generation and the associated fuel cycle, from medical, industrial, agricultural and research uses of radioactive materials, from the extraction and processing of materials that are naturally slightly radioactive, such as phosphate ores, oil and gas, and from military nuclear programmes.



Decay of radioactivity of high-level waste resulting from reprocessing 1 t of fuel. The straight line shows the radioactivity of the uranium ore needed to produce 1 t of fuel. (Radioactivity is measured in becquerels (Bq). 1 GBq equals 10^9 Bq.)

The type of radioactive waste that gives rise to the greatest concern is that produced by the nuclear power industry, often called nuclear wastes. The raw material of nuclear power, uranium, is naturally radioactive, and the mining and processing of uranium ores result in large quantities of waste rock and mill tailings which still contain traces of uranium and the radioactive products into which it decays, such as radium and radon. Fission, the process of the splitting of uranium on which nuclear power depends, inevitably results in the production of new ("man-made") radioactive materials. In nuclear reactors these are largely retained in the fuel, but some may enter the coolant and be transported to different parts of the plant such as the heat exchangers. The neutrons produced in the fission process can induce radioactivity in materials through which they travel. These so-called activation products are produced in the fuel itself, in the cladding that surrounds it, in the coolant, and in the reactor's structural materials. With the exception of plutonium, an activation product which can itself be used as a nuclear fuel, these products are mostly unwanted by-products or wastes. The wastes retained in the fuel, over 95% in terms of radioactivity, are the ones that require most care because of the intense radiation they emit and the associated heat production. Those that enter or are produced in the coolant must be controlled so that no unacceptable amounts appear in any effluent from the plant and those produced in the reactor's structural materials require special techniques when reactors are decommissioned at the end of their useful lives.

Radioactive wastes from sources other than the nuclear industry, which in general give rise to less concern, have actually caused more harm as a result of occasions when they were not properly controlled. Most of the radioactive materials used in medical investigations, industrial measurement and quality control, research and geological exploration have relatively short half-lives, from a few hours to a few years, and, provided that they are not disposed of while still significantly radioactive, they pose no particular waste management problem. Powerful radioisotope sources used for medical treatment, the sterilisation of medical equipment, food irradiation, and some industrial processes, however, typically consist of materials such as cobalt-60 and caesium-137, with half-lives of about five and thirty years, respectively, and are potentially as dangerous as all but the most intensely radioactive nuclear wastes. There have been several examples of people being exposed to high doses of radiation as a result of the careless disposal of such radioisotope sources, of which the best known was at Goiana in Brazil in 1987, where 21 persons required intensive medical care, four of whom died as a result of their exposures.

The extraction and processing of large volumes of materials that contain traces of naturally radioactive materials can result in a concentration of the radioactivity in the waste streams. Examples are phosphate ore extraction for fertiliser production, and drilling for oil and gas. Such wastes are generally exempted from radioactive waste management regulations although their radioactivity concentrations may overlap with those of some categories of radioactive waste that are subject to regulation.

Military nuclear programmes have also resulted in the production of large quantities of radioactive wastes of all types. In some cases, particularly in the early days of military nuclear programmes in some countries, standards were well below those applied to civil nuclear programmes and serious waste-related accidents and environmental pollution occurred. The dismantling of nuclear weapons following disarmament agreements will result in further radioactive wastes requiring disposal if the materials are not used as fuel for nuclear reactors.

While this report deals mostly with wastes from civil nuclear power which give rise to the greatest concern, the approach and methods nevertheless also apply to radioactive wastes from other sources. In those few countries that have military wastes, the procedures and solutions are similar to those for wastes from civil nuclear power programmes.

Categories

Radioactive wastes can be solid, liquid or gaseous and may contain varying concentrations of a wide range of radioactive elements. Each radioactive element, or radionuclide, whether natural or man-made, has its characteristic half-life and radiation "signature", emitting radiation of a particular type and energy. The three main types of radiation are called *alpha*, *beta* and *gamma*. Alpha radiation has very little penetrating power and can be stopped just by a sheet of paper. Materials that emit alpha radiation, however, can be dangerous if taken into the body, where the alpha particles can bombard internal organs. Beta radiation is more penetrating than alpha radiation, but can be stopped by a sheet of metal foil. Gamma radiation is even more penetrating and can only be stopped by thick layers of concrete, steel or lead. For convenience, the wastes are normally classified into a small number of categories, with all the wastes in any particular category being managed in the same general way. The categories are generally based on the concentrations of radioactive material present in the wastes, and hence on the intensity of the radiation they emit, and on the times for which the constituents remain radioactive, which can range from a few decades to many millions of years.

The main categories are:

- *low-level wastes* – these emit so little radiation that they need no special shielding and can be handled using simple protective measures such as rubber gloves. Most contain only trace amounts of long-lived radionuclides; those that contain more than trace quantities are managed together with long-lived medium-level wastes;

- *medium or intermediate-level wastes* – these need shielding, generally metal or concrete, and remote-handling devices to protect people from the radiation they emit. Some medium-level wastes only contain short-lived radionuclides, those which contain radionuclides such as plutonium and transuranic elements like neptunium and americium, essentially those that emit alpha radiation, are long-lived, and are sometimes classified as alpha wastes;

- *high-level wastes* – these need heavy shielding and remote-handling devices. The intensity of the radiation they emit is so high that they become physically hot and remain so for many decades, during which time some method of removing the heat must be provided. This category covers both irradiated fuel discharged from reactors (if not reprocessed in order to recover the residual uranium and plutonium) and the highly radioactive wastes that remain after reprocessing.

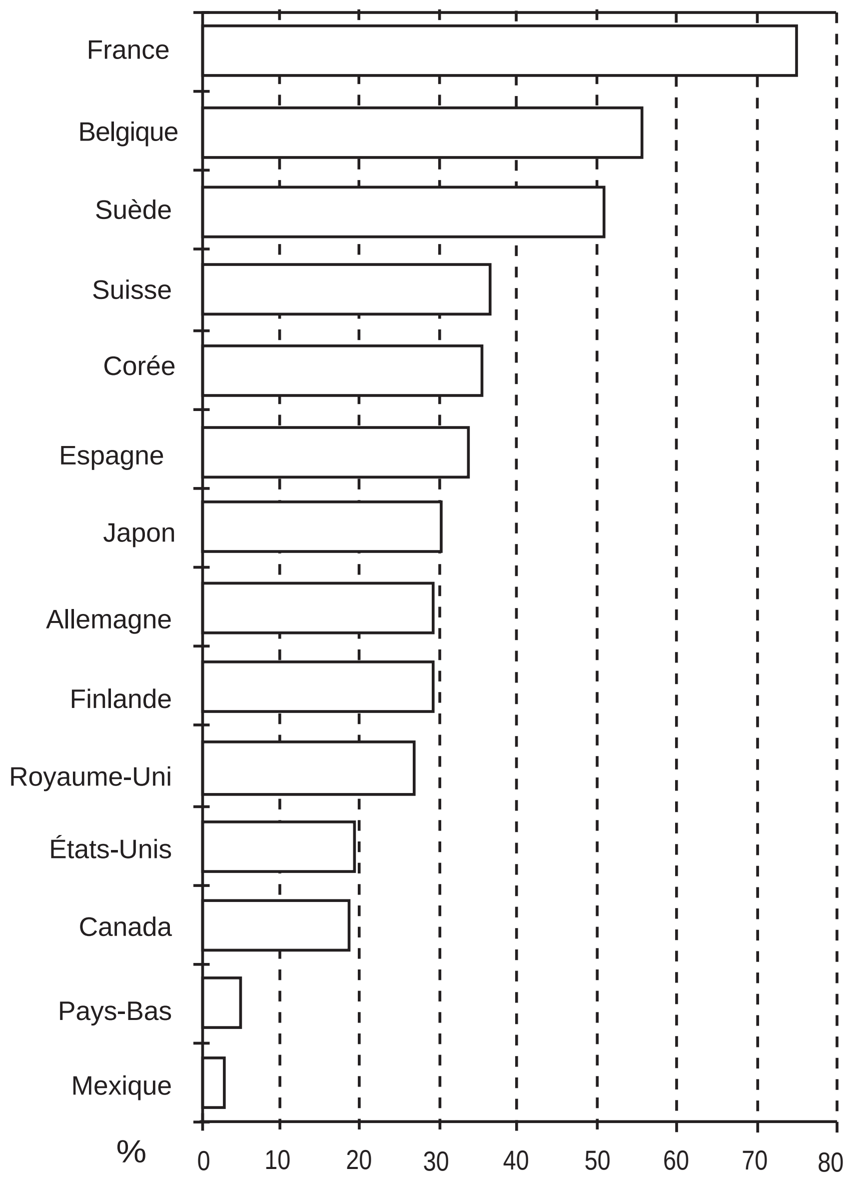
In time, through the process of radioactive decay, high-level waste becomes medium-level and then low-level waste; eventually the radioactivity decays away entirely.

Quantities

The energy concentration of nuclear fuel is enormous: the energy released from the complete fissioning of 1 tonnes of uranium would be equivalent to burning 2.7 million tonnes of coal, and the amount of waste resulting from nuclear power is therefore very much smaller than that from fossil-fuelled electricity generation. For a typical large modern pressurised-water reactor (PWR), for example, the generation of 1 gigawatt (1 GW, or one billion watts) of electricity for one year results in about 1.2 tonnes of waste fission products; a coal-fired station of similar size produces, in one year, up to 500 000 tonnes of ash, containing about 100 tonnes of chemically toxic heavy metals and other toxic elements, plus about 5 million tonnes of gaseous wastes, principally carbon dioxide. A 1-GW station can power 1 million 1-kW electric heaters continuously or provide the total electricity needs of between 1 and 2 million people in a typical OECD country, so the actual weight of radioactive waste produced, per person benefiting from the electricity, is minute: about 1 g a year.

The fission products, and most of the activation products, are created in the fuel itself. These wastes are retained within the reactor till the fuel is replaced, typically after two or three years of operation. During 1994, nuclear power stations in OECD countries generated a total of about 1830 terawatt-hours (TWh) of electricity – 24.4% of total OECD electricity requirements. This resulted in the production of more than 8,000 t of spent fuel.

Nuclear Share of Total Electricity Generation (31 December 1994)



Indicative volumes of packaged radioactive waste
(excluding shielding)
for a modern PWR of 1 GW capacity, during 1 year

Reprocessing route		**Direct disposal route**	
Low-level waste	200 m^3	Low-level waste	200 m^3
Medium-level waste	70 m^3	Medium-level waste	70 m^3
Vitrified high-level waste	2.5 m^3	High-level waste	0 m^3
Spent fuel	0	Spent fuel	10 m^3

The volumes of waste of different categories associated with this amount of electricity generation depends mainly on the way in which the spent fuel is subsequently managed. The main options are reprocessing of the spent fuel followed by disposal of the resulting wastes, and direct disposal of the spent fuel, as described in Chapter 4. The total amount of radioactivity is, of course, the same for both options, but the volumes of the different categories of waste to be dealt with are different: reprocessing results in less high-level waste but more low and medium-level waste.

In addition, reusing the recovered uranium and plutonium from reprocessing reduces the amount of new uranium that has to be mined and thus reduces the amount of mining and milling waste produced. In addition to the wastes that are created in the nuclear fuel, the intense flux of neutrons within the reactor creates activation products in the structural components, which result in the structure itself becoming radioactive and remaining so even after energy production has ceased and all the fuel removed. This radioactivity must be safely dealt with when the station is eventually dismantled and the site restored for unrestricted use. The quantities of this decommissioning waste are larger than the quantities of waste created in the fuel itself, but most of it is low-level, consisting typically of slightly radioactive steel and concrete.

Toxicity and hazard

The toxicity of radioactive wastes varies over a very wide range. Some are comparable to the most toxic industrial wastes; while at the other extreme, many are only very slightly radioactive and no more toxic than common everyday materials containing traces of natural radioactivity, such as garden fertiliser and

Brazil nuts. Although some radioactive wastes are chemically toxic, in general their toxicity is almost entirely due to the radiation they emit.

The toxicity of a particular radionuclide depends on the type and intensity of the radiation it emits and on the way it enters and interacts with the body. All radiation can in principle harm living tissue (strictly speaking we should use the term "ionising radiation" because the basic mechanism of the interaction is through ionisation, the production of electrically charged particles called "ions"; non-ionising radiation such as that produced by ultra-violet lamps, lasers and even sunshine can also be hazardous in some circumstances).

When radiation interacts with living tissue, it sets off a complex sequence of physical and chemical changes in the cells through which it passes. The critical targets are thought to be the DNA macromolecules that carry the genetic information that controls the development and division of the cells. The fact that our bodies can withstand the constant bombardment by radiation from natural sources without apparent ill effect suggests that virtually all the damage caused to cells by radiation is either unimportant or readily repaired by the body's natural repair mechanisms. There are, however, two ways in which the damage can be important: it can kill some of the cells, or it can transform them in ways that affect their function. The effects of cell killing are usually seen soon after the radiation exposure that causes them; they are therefore called the early, or acute effects of radiation. The effects of cell transformation can take many years to appear, or may only appear in subsequent generations; they are therefore called the delayed effects of radiation. Both types of effect can be caused either by radiation entering the body from outside, or by internal radiation, following the inhalation or ingestion of radioactive material.

Early effects

An adult person contains about 60 million million cells. Several million of these die naturally every day and are replaced by new ones. Cells that are killed as a result of damage by radiation or other agents, such as chemicals, are normally replaced by new ones within a few days or weeks. The treatment of cancers by radiation, of course, is based on the process of cell killing, with particular care being taken to ensure that only the cancerous cells are irradiated. However, if a sufficiently large number of cells are killed in a period too short to permit natural replacement, the function of the body can be rapidly and seriously affected. Symptoms include skin burns (for external radiation only) and vomiting and, at high enough doses, death can result within days or weeks. Radiation can only produce these early effects at extremely high doses, delivered in a short time, typical of the doses experienced by the victims of the Hiroshima and

Nagasaki nuclear weapons and in accidents such as Chernobyl and Goiana. There is a threshold dose below which no harmful early effects are seen. The threshold dose is about 500 times greater than the average dose received each year from the natural background.

Delayed effects

A radiation dose that is below the threshold for early effects can still cause cell transformations or mutations. These do not necessarily lead to any harmful effects; indeed many such changes occur naturally during the lifetime of any organism. They may, however, result in the development of cancer many years after the radiation dose is received or, in the case of cells responsible for reproduction, in hereditary effects in later generations.

Most of the information we have about the ability of radiation to cause cancer in humans comes from extensive studies of the survivors of the Hiroshima and Nagasaki bombings, and of limited numbers of people who have been exposed to high doses of radiation as a result of their occupation or medical treatment. Little direct information is available about the effects of small doses, such as those resulting from the routine operations of nuclear installations. Such doses are generally below average annual doses from natural background sources and well below those experienced by some people who live in high background radiation areas, for example at high altitudes. People who live in such areas do not have higher than average cancer rates, and it is possible that small doses of radiation have no harmful effects whatever. Nevertheless, it is assumed, for the purposes of radiation protection, that there is no threshold below which radiation is entirely harmless.

No direct evidence of hereditary effects of radiation in humans at any dose level has yet come to light, even among the offspring of the bomb survivors, the most heavily irradiated population studied, so possible effects have to be estimated by extrapolation from animal studies. Again it is assumed, for the purposes of radiation protection, that there is no threshold, but the total harm caused by a given dose of radiation is dominated by harm to the exposed individual rather than to his or her offspring.

Chemical and radiotoxicity

It is important to recognise the differences between radioactive materials and those chemically toxic materials which can also cause cancer, hereditary damage and acute effects including death, albeit by different mechanisms. All radioactive materials lose their toxicity in time as their radioactivity decays, but while some chemicals lose their toxicity as a result of chemical changes in the environment; many, including some that are carcinogenic, retain their toxicity for ever.

There are several other important differences between radioactive and chemically toxic wastes. Far more is known about the biological and environmental effects of radioactive wastes. They are more easily detectable, even at very low concentrations, and they are subject to more stringent regulations. A greater public appreciation of these differences should help to put the issue of radioactive waste management into perspective.

A further useful perspective can be gained by comparisons of the inherent toxicity, or "toxic potential," of radioactive and other wastes. Toxic potential is a measure of the maximum theoretical harm that could result from a given quantity of waste. Comparisons can be made between the toxic potential of the annual production of high-level radioactive waste in a typical industrial country (assuming that all its electricity was generated by nuclear power) and that of the annual production of typical toxic chemical wastes. Such comparisons indicate that the toxic potential of the radioactive waste will decay to that of typical chemical wastes after about 1000 years and thereafter continue to fall.

Considerations of toxic potential, however, do not give any measure of actual hazard, which can only be arrived at by considering in detail the effectiveness of every stage of the waste management process and the precise pathways of waste material through the environment and its consequent uptake by people. The hazards that may result from radioactive waste management are discussed in Chapter 4.

The crucial difference between the way chemically toxic and radiotoxic wastes are managed is that while virtually all chemically toxic wastes are disposed of in surface or near-surface landfill sites, most radioactive wastes (except those with low levels of radioactivity and short lives) will be disposed of deep underground in engineered repositories sited in suitable geological formations.

Chapter 2

SAFETY AND ENVIRONMENTAL PROTECTION

Summary

The primary objective in the management of radioactive wastes is to protect current and future generations from unacceptable exposures of radiation from man-made radioactive materials.

Radiation protection is based on the recommendations of the International Commission on Radiological Protection. The ICRP recommendations are based on three principles, applied to all activities with an element of radiological risk. These principles are: justification; optimisation of protection; and individual dose and risk limitation.

The ICRP and other international bodies make additional recommendations specific to waste disposal: that future generations be as highly protected as present ones, and that the safety of disposal sites should not depend on maintenance beyond a certain time limit.

National regulatory requirements are based on international recommendations, but can vary between countries. One of the roles of international bodies such as the Nuclear Energy Agency is to harmonise these national regulations.

In all OECD countries responsibility for safety lies with the operators of nuclear facilities. Responsibility for regulation lies with governments who define the legal framework within which operators have to work. Responsibility for enforcing regulations lies with regulatory bodies, generally independent of operators and government, who award licences to sites satisfying government regulations, and withdraw licences from sites failing to satisfy government regulations.

Objectives of radioactive waste management

The primary objective in the management of radioactive wastes is to protect current and future generations from unacceptable exposures to radiation from man-made radioactive materials. The protection of current generations is a common requirement for most potentially hazardous industrial activities, and regulations and the ethical considerations on which they are based have been extensively developed. The need to protect future generations from long-lived radioactive wastes has led to fundamental ethical questions about the degree of responsibility that today's generation should have for future generations. Radioactive wastes are not unique in raising such questions and some of the approaches that are being developed for dealing with the radioactive waste problem are beginning to be considered for other industrial activities with long-term consequences. It is such considerations that have led to the wide technical acceptance of deep geological disposal, with no need for surveillance or any other action by future generations, as currently the most promising option for meeting both the ethical and the technical requirements for long-lived radioactive wastes.

In addition to protecting people, now and in the future, there is also a need to protect the natural environment, but since humans are among the most sensitive life-forms to radiation, proper protection of people can be assumed to lead also to proper protection of other species. In addition, in accordance with the principle of sustainable development, any constraints on future generations, such as limitations on land use or access to potentially valuable natural resources, should be minimised as far as practicable.

Radiation protection

Radiation protection, which dates back to the development of medical uses of radiation and radioactive materials during the early decades of the century, is based on the recommendations of the International Commission on Radiological Protection (ICRP), an independent body of medical and scientific experts. Periodically updated in the light of the latest scientific knowledge, such as that reviewed by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the ICRP recommendations have developed as understanding and appreciation of risks have grown and are based on three fundamental principles:

- *Justification* – Any practice that involves additional radiation exposure should be justified by the benefits that result.

- *Optimisation of protection* – All exposures should be kept *A*s *L*ow *A*s *R*easonably *A*chievable or Practicable, commonly shortened to ALARA (or ALARP), economic and social factors being taken into account.
- *Individual dose and risk limitation* – Individual exposures are subject to dose limits and control of risk.

These principles are only applicable to sources or practices that are capable of control, and thus exclude important sources of exposure such as the majority of natural sources, which are essentially inescapable.

The first ICRP principle is based on the need to avoid unnecessary radiation exposures, since it must be assumed, for the purposes of protection, that all exposures, however small, may carry some risk and must therefore be justified by some benefits. In the case of nuclear power, for example, future generations will benefit by being able to use coal, oil and gas as raw materials for chemicals, plastics, medicines and perhaps even proteins for food, but only if they are not all burned up by preceding generations for the production of energy. In the case of radioactive waste management, what must be justified is the practice that gives rise to the waste, whether it be the generation of electricity, or the medical, industrial or research uses of radioactive materials.

The second ICRP principle, like the first, is based on the assumption that no radiation dose is entirely free of risk. All radiation exposures, therefore, should be made as low as it is reasonably possible to make them. The principle includes the word "reasonable" because a point must come where the cost of achieving a further reduction of an already low risk cannot be justified. For example, most motorways have central crash barriers, but no-one would suggest installing them on quiet country roads, even though they would doubtless increase road safety somewhat. The process of finding an appropriate balance between the benefits of reducing a risk and the costs of achieving such a reduction is called the "optimisation of protection."

The third ICRP principle is that doses and risks should not be allowed to exceed specified limits. The limits are based on comparisons between the risks associated with radiation exposures and other types of risk. Continued exposure just below the limits might just be tolerable, but not readily accepted unless there was a clear benefit to the exposed individual. The limits are normally specified in national regulations. However, while exceeding a limit would be a serious matter for the purposes of the rules, it does not imply serious harm to the person exposed, just as a car exceeding the speed limit does not automatically lead to a serious road accident.

International recommendations for radioactive waste disposal

The management of radioactive waste has been the subject of international co-operation since the early days of civil nuclear power. In addition to co-ordinating national R&D and implementation policies, national and international organisations have worked together to develop the criteria and standards that form the basis of regulation in all countries that have to deal with radioactive wastes. In addition to the basic principles relating to radiation protection, two additional principles have been widely accepted which relate specifically to the protection of future generations from current radioactive waste disposal practices:

- the level of protection of future generations should be at least equivalent to that of the present generation;
- safety should not depend on the active maintenance of the disposal system by future generations beyond a limited period of active surveillance, typically taken to be around 300 years.

National criteria, regulations and standards

National criteria, regulations and standards are based on international recommendations, but may vary from country to country depending on particular economic, socio-political, legal and institutional structures and general geographical conditions. Differences of emphasis can be found in:

- whether limits are expressed in terms of dose or risk;
- whether individual or collective dose or risk limits are used (collective dose or risk is a measure of the total dose or risk to a group of people or a whole population. It is the average dose or risk multiplied by the number of people in the group or population);
- the level of detail of the criteria, for example the use of special criteria for certain scenarios such as inadvertent intrusion;
- the period for which compliance with the dose or risk limits has to be shown;
- the level at which concentrations of radionuclides are so low as to be deemed to be “Below Regulatory Concern” or de *minimis* and therefore not subject to specific regulations applied to radioactive wastes. Such wastes, sometimes classified as “very low-level wastes” or “exempt

wastes" are likely to be of particular importance in the context of the decommissioning of nuclear facilities, since some of the materials to be dealt with are only very slightly radioactive.

International bodies such as the NEA play a major role in harmonising regulations and standards, and there is, despite these differences, a broad agreement about overall health and safety requirements and about the need to take uncertainties in safety assessment into account by providing appropriate safety margins.

In all OECD countries, responsibility for safety lies with the operators of nuclear facilities while responsibility for regulation lies with governments, who define and implement the legal framework within which the operators have to work. The objectives of the legislation are generally:

- to provide a statutory basis for establishing a regulatory body;
- to empower the regulatory body to establish and enforce the necessary regulations;
- to provide a legal basis for ensuring that facilities are sited, designed, constructed, operated and decommissioned without undue risk to workers, the general public or the environment;
- to ensure the provision of adequate third party indemnity in the event of any harm that may result from routine operations or accidents.

The regulatory body is responsible for the surveillance and control of all matters relating to safety. In general it is independent of other government agencies and of the operators and vendors of nuclear installations, and can ensure compliance with all necessary safety regulations through a licensing process. Licensing is in effect a continuous process throughout the life of an installation, since it applies to all stages from initial siting through operation to final decommissioning or, in the case of a disposal operation, final closure. All installations are subject to regular inspection and monitoring, and a license can be revoked at any stage if the regulator is not satisfied about safety.

ANNEX

National Radioactive Waste Management Programmes in NEA Countries

BELGIUM

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

Nuclear energy provides 55.8% of Belgium's electricity, from seven reactors with an installed capacity of 5.5 GW (1994).

Until 1974 spent fuel was reprocessed at the EUROCHEMIC plant. It is now reprocessed at La Hague, France, and the resulting wastes will be returned to Belgium for temporary storage and final disposal.

NATIONAL WASTE MANAGEMENT STRATEGY

Wastes other than reprocessing wastes are conditioned, either on the site where they arise or in a central processing facility at the Mol-Dessel site managed and operated by Belgoprocess, the subsidiary company of ONDRAF. All wastes will be stored at Mol-Dessel until appropriate disposal facilities are developed.

Wastes containing short-lived low-level radionuclides will be disposed of above ground level or deep underground, depending on the outcome of current evaluations. Wastes containing long-lived medium-level radionuclides, and high-level and heat-generating wastes arising from reprocessing, will be disposed of deep underground.

RESPONSIBILITIES

The National Agency for Radioactive Waste and Enriched Fissile Materials (ONDRAF) is an autonomous public agency operating under the guardianship of the Minister having energy among his responsibilities. It is responsible for the management of all radioactive wastes produced in Belgium. It is financed by the waste producers.

ONDRAF also manages a special fund for the financing of long-term operations, sponsored by the waste producers.

STORAGE

Spent fuel is stored at the power stations until it is sent for reprocessing. No central spent fuel storage facility is therefore needed.

All conditioned wastes awaiting disposal, including returned reprocessing wastes, are or will be held at Mol-Dessel on the Belgoprocess site:

- Conditioned low-level wastes are stored in prefabricated concrete buildings. Those being returned from La Hague are stored in a new facility.
- Conditioned medium-level wastes resulting from reprocessing at the EUROCHEMIC plant and from nuclear power plants are held in shielded storage bunkers. Those being returned from La Hague are stored in a new facility.
- High-level wastes from EUROCHEMIC, vitrified in the PAMELA plant, are stored in air-cooled storage pits in a bunker building. Those being returned from La Hague are stored in a new facility.

DISPOSAL

ONDRAF is co-ordinating research and development of final disposal for conditioned low-level and short-lived wastes in continental formations, and in deep clay layers for long-lived high-level wastes. The work is carried out in co-operation with various national and international organisations, as well as with the waste producers, who finance the programmes.

No decision has yet been taken on the disposal system to be used for short-lived low-level wastes. Several zones which might be acceptable for surface or near-surface repositories have been identified. In addition to surface or near-surface disposal, ONDRAF is also evaluating disposal in deep formations on the same site considered for high-level and other long-lived wastes.

A study of potential deep geological formations, performed by the National Nuclear Research Centre (CEN), resulted in the decision to investigate the Boom clay formation in the Mol-Dessel area. An underground laboratory has been constructed in this formation at a depth of 230 m, and an extensive research programme will continue for several years.

While no final repository design has yet been agreed, the underground facilities will probably consist of a network of interconnected circular tunnels, 3 to 4 m in diameter. The high-level waste canisters (vitrified waste) could be placed directly in the central axes of the galleries. Other waste packages could be placed in separate galleries. The galleries would be backfilled to provide a good support structure, possibly using the excavated clay, which might be mixed with other natural or synthetic material. Site confirmation studies and demonstration operations will probably continue until around 2015, and would be followed by final conceptual design, licensing and construction, with waste emplacement due to start around 2035.

CANADA

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

Nuclear energy provides 18.8% of Canada's electricity, from 22 reactors with an installed capacity of 15.4 GW (1994).

Spent fuel is currently stored at the power stations pending the development of disposal facilities. Research has been carried out on reprocessing but there are currently no plans to use the technology.

NATIONAL WASTE MANAGEMENT STRATEGY

Uranium has been mined since the early 1930s and over 200 million tonnes of tailings have been generated. Uranium tailings are decommissioned on site. Successful decommissioning has been achieved at a few sites in Saskatchewan and Ontario. Other sites are either being decommissioned or are still in operation.

All wastes from nuclear power generation are stored pending the development of permanent disposal facilities.

Wastes produced by AECL from isotope production and from R&D activities are currently stored at the Chalk River and Whiteshell Laboratories. Waste produced by universities, hospitals and a number of other producers are also stored at the Chalk River Laboratories. AECL is currently seeking a construction license for a prototype Intrusion Resistant Underground Structure (IRUS) for disposal of short-lived wastes.

Spent fuel will be disposed of 500 to 1000 m underground in the rock of the Canadian Shield. Ontario Hydro and AECL are examining options for the disposal of other long-lived wastes.

RESPONSIBILITIES

The primary responsibility for the management of radioactive wastes in accordance with regulatory criteria established by the Atomic Energy Control Board (AECB) rests with the producers/owners of the wastes.

There are two federal government agencies with responsibilities in radioactive waste management: the AECB, the Canadian nuclear regulatory agency that was established in 1946 by the *Atomic Energy Control Act*, and AECL, which is responsible for research in radioactive waste management. The Low-level Radioactive Waste Management Office (LLRWMO), the federal agency responsible for the clean-up of historic low-level radioactive wastes that are the responsibility of the federal government, is operated out of AECL.

Funding for storage and disposal of low- and medium-level waste is the responsibility of the producers of the wastes. Research and development for new and improved management technologies is funded by AECL and Ontario Hydro.

Funding for the nuclear fuel waste management programme was principally provided by the Government of Canada until 1987. Ontario Hydro is currently providing substantial funding and is collecting funds from its customers which will be applied towards the cost of disposing of Ontario's spent fuel. Utilities in New Brunswick and Quebec have similar arrangements.

STORAGE

Spent fuel is stored at the power stations and will remain there until a disposal facility is in operation. The fuel is initially discharged to primary bays and, after a cooling period, transferred to auxiliary bays. Spent fuel is in dry storage at a number of sites. The systems allow for storage for up to 50 years, and this could be extended if necessary.

Low- and medium-level wastes are mostly stored at the Ontario Hydro Bruce Nuclear Power Development site and at AECL's Chalk River Laboratories and Whiteshell Laboratories. The facilities consist of concrete-lined trenches, tile holes, above-ground storage buildings, above-ground reinforced concrete structures, and in-ground steel containers in concrete-lined boreholes.

DISPOSAL

National policy encourages waste producers to establish disposal facilities for low- and medium-level wastes for their own needs.

AECL is in the process of obtaining regulatory approval to construct an Intrusion Resistant Underground Structure (IRUS) at the Chalk River Laboratories, consisting of reinforced concrete in-ground modules, each 30 m long, 20 m wide and 9 m deep. The packaged waste, in the form of steel drums, bales and standardised boxes, will be stacked in the modules, on a base of compacted buffer material, and the spaces between filled with sand. After the modules are filled, they will be covered with a concrete cap overlaid by an engineered cover containing barrier and drainage features.

Ontario Hydro, the largest producer of low-level wastes, is planning to have a disposal facility in operation by 2015. Three options are being considered:

- an independent facility;
- a facility to be co-located with a spent fuel disposal facility yet to be developed;
- collaboration with other producers and the federal government to develop a joint multi-user Canadian disposal facility.

The LLRWMO will develop, as required, a user-pay service for the disposal of low-level waste produced on an ongoing basis.

AECL has conducted a 16-year research programme to develop a disposal concept for spent nuclear fuel based on a geological repository in crystalline igneous rock of the Canadian Shield. The concept is based on burial, at depths of 500 to 1000 m, using a series of engineered and natural barriers. The major research facility is the Underground Research Laboratory, in Whiteshell, Manitoba.

The concept is currently undergoing a federal Environmental Assessment and Review Process. The issue of siting will not be addressed until the concept itself has been found to be technically feasible, safe and publicly acceptable. A decision is not expected before 1997. Ontario Hydro has approved a waste management strategy that has as an objective first disposal of nuclear fuel waste in 2025.

A Siting Task Force has been active for several years seeking to acquire a site for the long-term management of contaminated soils and wastes, mainly from the processing of radium and uranium ores, for which the federal government has assumed responsibility. The town of Deep River, Ontario, has volunteered to host a rock cavern disposal facility for these wastes, and an agreement in principle has been approved by the town in a referendum. If the government agrees to proceed, the facility is to be located on AECL's Chalk River Laboratories' property.

FINLAND

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

Nuclear energy provides 29.5% of Finland's electricity production, from four reactors with an installed total net capacity of 4 GW (1994).

In the past spent fuel from the two VVER reactors at Loviisa has been transported back to Russia after five years' storage at Loviisa. No reprocessing wastes have been returned back from Russia to Finland. This arrangement has been in accordance with the objectives of the Finnish nuclear waste management policy of November 1983. At the end of 1994 the Parliament approved an amendment to the *Nuclear Energy Act* stating that in the future Finland shall itself take care of all the nuclear wastes generated in the country. Consequently, the return of spent fuel back to Russia is not allowed after 1996.

To implement in practice the renewed policy of spent fuel management, the two Finnish power companies (Teollisuuden Voima Oy [TVO] and Imatran Voima Oy [IVO]) have agreed to co-operate for the final disposal of spent nuclear fuel. For this aim it was decided to establish a joint company which will start operating early in 1996.

NATIONAL WASTE MANAGEMENT STRATEGY

Operating wastes (low- and medium-level) are conditioned and stored on site at the power stations. Repositories for these wastes are either in operation (at the Olkiluoto power station site) or under construction (at the Loviisa power station site).

Spent fuel will be disposed of in a deep underground repository from 2020 on.

RESPONSIBILITIES

Each producer of nuclear waste is responsible for its safe management and disposal, and for the financing of these operations. The utilities levy funds for waste management during the operation of the nuclear power plants.

The main authority is the Ministry of Trade and Industry, supported by the Advisory Committee on Nuclear Energy. The State Nuclear Waste Management Fund supervises and handles financial liability issues.

Responsibility for the control of nuclear safety, including waste management, belongs to the Finnish Centre for Radiation and Nuclear Safety, supported by the Advisory Committee on Nuclear Safety.

STORAGE

Spent fuel and other wastes are stored at the power plants until they are disposed of in Finland.

As a result of the policy change of spent fuel management, the alternatives for increasing the interim storage capacity for spent fuel at the Loviisa power plant are being studied during 1995. The present capacity is for about 10 years of spent fuel of which less than half has been used in the previous practice of transporting it back to Russia.

At Olkiluoto, the spent fuel is cooled for a few years in water pools in the reactor building, then transferred to a separate waterpool-type facility on the site for long-term storage. The design of this facility allows for a gradual expansion of capacity to meet the requirements for storage space for the entire lifetime of the current reactors.

Before transfer to the final repository the reactor wastes are temporarily stored and conditioned at the power plants.

DISPOSAL

The nuclear power plant sites at Olkiluoto and Loviisa were chosen at the end of the 1970s as candidate locations for repositories for low- and medium-level wastes. Comprehensive investigation programmes have confirmed the suitability of both sites. A repository constructed at Olkiluoto has been in operation since May 1992 and another repository is under construction at Loviisa.

The Olkiluoto repository consists of two separate vertical silos excavated in crystalline rock under the Olkiluoto island between 60 and 100 m below sea level. The silo for bituminised medium-level wastes consists of a thick-walled concrete silo inside the rock silo. No backfilling will be used inside the concrete silo. The empty space between the concrete silo and the rock will be filled with crushed rock. The silo for dry operating wastes is of shotcreted rock. In both silos the waste drums are emplaced within concrete boxes each containing 16 drums.

The Loviisa repository is planned to consist of a cavern for immobilised wet wastes and tunnels for dry operating wastes, at depths of 110 m. The immobilised wet wastes will be placed in concrete containers surrounded by concrete walls and a backfilling of crushed rock around the concrete walls. The repository is planned to be commissioned in 1997.

The repository concept being developed for spent fuel is emplacement in boreholes drilled in the floor of tunnels to be excavated at a depth of about 500 m in good-quality crystalline rock. The spent fuel will be encapsulated in double-layered copper-steel canisters, the spaces between the fuel elements being filled with suitable granular material. A new design concept is being studied for the inner layer based on a nodular cast iron insert eliminating the need of stabilising filler inside the canister. The gaps between the canisters and the rock walls of the boreholes will be filled with compacted bentonite and the tunnels backfilled with a mixture of sand and bentonite.

Preliminary site investigations have been completed at five candidate sites. A safety analysis, based on the repository design described above, concluded that the planned disposal system fulfils the safety requirements and that suitable places for the repository could be found at each of the five investigation sites. Three sites have been selected for further detailed characterisation and a final choice should be made in the year 2000. Supplementary investigations will then be carried out at the chosen site until 2010, and, subject to licensing procedures, commissioning is planned to take place in 2020.

FRANCE

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

Nuclear energy provides approximately 75% of France's electricity, from 56 reactors with an installed capacity of about 58 GW (1995). Four reactors with a capacity of 5.6 GW are under construction.

Spent fuel is reprocessed at La Hague (enriched uranium) and Marcoule (natural uranium). Long-lived high-level waste resulting from reprocessing are stored on site where they are produced, pending a definite solution.

NATIONAL WASTE MANAGEMENT STRATEGY

Short-lived wastes are disposed of in surface repositories. The Centre de la Manche has entered in its closing phase after receiving waste from 1969 to 1994. The Centre de l'Aube was commissioned in 1992 and should satisfy the country's needs for several decades.

With regard to long-lived high-level wastes, Parliament voted a law in 1991 prescribing that research options be pursued. The government and Parliament have agreed to meet again in 2006 in order to resolve the issue in light of the results obtained. If deep geological disposal is chosen, the plan would be for a deposit to be commissioned before 2020.

RESPONSIBILITIES

The National Agency for Radioactive Waste Management (ANDRA) is responsible for all long-term operations associated with radioactive waste management, namely:

- to participate, in co-operation notabily with the Commissariat à l'énergie atomique (CEA), in the definition and activities of R&D programmes relating to radioactive waste management;

- to ensure the management of long-term storage facilities either directly or through an agent acting on its behalf;

- to design, site and build new storage facilities in light of long-term prospects for the production and management of waste, and to undertake any necessary study to this end, namely the implementation and operation of underground laboratories to study deep geological formations;

- to define, in accordance with safety rules, specifications for processing and storing radioactive waste;

- to list the state and location of all radioactive waste in the country.

ANDRA is funded by the waste producers. It also receives a small governmental grant covering the costs of establishing the national inventory.

The waste producers are responsible for all the operations needed to put the wastes into a form suitable for disposal, and consistent with the ANDRA specifications. ANDRA controls the application of these specifications by the waste producers.

Public authorities are responsible for the broad outline of waste management policy, legislation and technical regulations. Safety authorities control ANDRA's operations; radioactive waste management facilities are basic nuclear facilities and are consequently subject to the regulations in force.

ANDRA reports to the Ministers responsible for the Industry, Research and the Environment.

STORAGE

After conditioning short-lived low-level wastes are stored in ANDRA's storage facilities (currently the Centre de l'Aube).

Spent fuel is stored in pools at the reactor site as soon as it is removed from the reactor. After being transferred to the reprocessing plant, it is stored in pools at the front end of the process line.

After reprocessing, high-level waste are stored, first in liquid form in high-integrity ponds, then after vitrification, in air-cooled structures. Long-lived waste are also stored in structures on the site under the responsibility of the producers, until the government and the Parliament decide upon a final solution.

DISPOSAL

Since 1969 short-lived waste are disposed of in surface facilities at Centre de la Manche. Concrete “monoliths” and “tumuli” containing waste are capped with a leak-proof cover to protect the waste from rainfall and a layer of seeded topsoil. The Centre contains a little over 500 000 m^3 of waste and does not receive any waste any more.

A new facility, the Centre de l’Aube, started operations in 1992. Packages are placed in engineered structures made of concrete. Once filled, each structure will be capped by a concrete slab. A leak-proof cover will then cover all workings. The Centre can accommodate 1 million cubic metres of waste and will remain in operation for several decades.

Long-lived high-level radioactive waste are undergoing extensive research today. One option deals with reversible and non-reversible disposal in deep geological formations, notably through the creation of underground laboratories.

Following a consultation period with the public, the government, on the recommendation of a “negotiator”, has authorised ANDRA to undertake field studies in four departments: Meuse, Haute-Marne and Gard for deep clay formations, and Vienne for granite. In order to specify the siting conditions for ground characterisation laboratories, ANDRA must propose to public authorities a location for two of such laboratories to be constructed somewhere in those four departments.

GERMANY

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

Nuclear energy provides 29.3% of Germany's electricity, from 21 reactors with an installed capacity of 22.6 GW (1994).

Spent fuel is stored at the reactor sites for up to 10 years. Some is sent abroad for reprocessing or to central interim storage facilities. Spent fuel stored in central interim storage facilities will be reprocessed or conditioned for emplacement in a repository, when the appropriate facilities are available.

NATIONAL WASTE MANAGEMENT STRATEGY

All categories of waste will be disposed of deep underground, after an appropriate period of storage. More particularly, the steps are as follows: (1) interim storage; (2) reprocessing or conditioning; and (3) disposal.

RESPONSIBILITIES

The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) is the competent authority for radioactive waste management, and supervises the licensing authorities in the Federal States and the Federal Office for Radiation Protection (BfS). It is advised by the Reactor Safety Commission and the Radiation Protection Commission.

The Federal Minister for Research and Technology is responsible for basic research and development work on radioactive waste and disposal.

The Federal States are the licensing and supervising authorities for most of the nuclear installations. Repositories are licensed by the Federal State concerned, and supervised by BfS. Spent fuel and conditioned high-level waste interim storage facilities are licensed by BfS, and supervised by the Federal State concerned.

The Federal Government is responsible for the planning, construction and operation of repositories for radioactive waste, with the BfS as the responsible authority. The Federal States are obliged to build collection points for the interim storage of the radioactive wastes arising in their area from the application of radioisotopes in industry, research and medicine. All other waste management procedures (*i.e.*, storage, reprocessing, waste conditioning, transport and interim storage) are the responsibility of the waste producers (*e.g.*, the operators of nuclear power plants). The German Company for Construction and Operation of Repositories (DBE) is involved in the construction of repositories and will operate them on behalf of BfS.

All costs associated with radioactive waste and spent fuel management are borne by the waste producers. The site-specific costs for research and development, as well as investigation and construction of repositories are financed by the BMU but reimbursed by the waste producers on an annual basis. Basic research and development work is financed by the Federal Minister for Research and Technology.

STORAGE

Some wastes with negligible heat generation are stored for an interim period on the sites where they are produced, others in interim storage facilities and collection points of the Federal States.

Spent fuel is stored in ponds at the power stations and central interim stores exist at Gorleben, Ahaus and Greifswald. The first two of the central facilities are for the dry storage of spent fuel elements in storage flasks. Greifswald is a pool-type facility. This will be replaced by a dry-storage facility in 1996 at the same site.

DISPOSAL

Since the early 1960s the policy has been to dispose of all radioactive wastes deep underground, concentrating initially on salt domes.

Research and development into deep disposal has been executed since 1965, mainly using the former salt mine at Asse. Demonstrations of low- and medium-level waste disposal were carried out until 1978. R&D work now focusses on long-term safety of high-level waste.

A site at Gorleben has been studied since it was nominated by the State of Lower Saxony and the Federal Government in 1977. The repository would be built at a depth of about 900 m in a salt dome below a gypsum top cap. Wastes with negligible heat generation would be stacked in disposal rooms. Heat generating wastes would be placed in galleries or in vertical boreholes. Underground tests and detailed repository designs should be completed by the late 1990s and, if approved, the repository is scheduled to become operational in 2010 at the earliest.

A former iron ore mine at Konrad, at depths between 800 and 1300 m, was identified as a possible repository site for low- and medium-level wastes with negligible heat production within the framework of a research and development programme between 1975 and 1982. The packaged wastes would be emplaced in chambers with an average diameter of 7 m and up to 1000 m long. The licensing procedure with an additional programme of underground exploration and safety assessment began in 1982 and a decision on the licence application is expected soon.

The former salt mine at Morsleben in the former German Democratic Republic has been used since 1981 for the disposal of low- and medium-level wastes, following several years of investigation and test operations. The total volume of underground openings is about 5 million cubic metres. On reunification, BfS became responsible for the repository. Approval for continuing operation has been granted, and a new licence will have to be sought in the year 2000 for use of the site to continue.

ITALY

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

There are currently no operating nuclear power stations in Italy. The three existing power stations have been shut down, and construction of a further station has been halted.

Some of the spent fuel from past power station operations is being reprocessed at Sellafield, U.K., with the resulting wastes being returned to Italy. The remaining spent fuel is stored at the power stations.

NATIONAL WASTE MANAGEMENT STRATEGY

Wastes from power plants and experimental fuel cycle facilities are stored at their point of origin. Wastes from medicine, industry and research are collected for temporary storage by NUCLECO or other private operators.

Work has been carried out on ultimate disposal, but no political decision has been taken and priority is being given to the realisation of a centralised interim storage facility.

RESPONSIBILITIES

In January 1994 the Italian Parliament approved a law for the creation of the National Agency for Environmental Protection (ANPA). Under this law, all the tasks and human and financial resources of ENEA/DISP (Directorate for Nuclear Safety and Health Protection) have been moved from ENEA (National Agency for New Technologies, Energy and the Environment) and assigned to ANPA.

ANPA/DISP now oversees the management of radioactive waste, serving as regulator.

ENEL (National Electric Energy Agency) is the government agency responsible for all electric power production. It owns the nuclear power stations and is responsible, under the control of ANPA/DISP, for treatment, conditioning and temporary storage of radioactive wastes produced by nuclear power plants, including spent fuel.

ENEA is responsible for R&D activities on radioactive waste management (treatment, conditioning, and characterisation of waste forms) and for disposal (site selection, characterisation and implementation).

NUCLECO SpA is a company owned by ENI and ENEA, supplying services for collection, storage, treatment and conditioning of low- and medium-level wastes.

STORAGE

Most of the radioactive inventory in Italy (apart from spent fuel) is in the high-level waste stream from experimental reprocessing activities at the ENEA EUREX plant. This is stored in liquid form in stainless steel tanks. Different options for its solidification are being examined.

Short-lived low- and medium-level wastes are stored, mainly at the production sites, awaiting the development of disposal facilities. Most of them remain to be treated and conditioned.

High-level and other long-lived wastes, coming from reprocessing abroad and from the domestic treatment of wastes from the closed ENEA fuel cycle experimental facilities, need to be stored in an engineered facility before their final disposal. This may be located at the same site as the nuclear plant of origin or, preferably, in a central interim storage site.

Spent fuel, apart from that already sent abroad for reprocessing, is stored in cooling ponds at the reactor sites. The two options being examined are reprocessing abroad or long-term interim storage in Italy pending final disposal.

DISPOSAL

During the 1970s and 1980s ENEA carried out several studies on deep geological disposal of high-level and other long-lived wastes. Clay was selected as the reference geological formation and studies performed on different clay formations in various parts of Italy.

Performance assessments were also carried out, including participation in the EC PAGIS study. Work is continuing under EC Cost Shared Actions.

Parallel investigations have been done on the final disposal of low- and short-lived medium-level wastes. At the end of these studies, a list of possible sites for the construction of a national repository was sent by ENEA to the Ministry of Industry.

JAPAN

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

Nuclear energy provided 30.1% of Japan's electricity in 1994. Nuclear power generation capacity totalled 41.4 GW (50 units including a prototype advanced thermal reactor) in September 1995. Four reactors with a capacity of 4.2 GW are under construction.

Spent fuel is being reprocessed in France and the U.K. and at Tokai; further reprocessing capacity is under construction. Waste resulting from reprocessing abroad is being returned to Japan for storage and disposal.

NATIONAL WASTE MANAGEMENT STRATEGY

Low-level wastes are disposed of in the near-surface facility at Rokkasho-mura.

Vitrified wastes resulting from reprocessing are stored for 30-50 years for cooling, before disposal deep underground.

RESPONSIBILITIES

The Government is responsible for establishing safety criteria, guidelines and regulations for the shallow land disposal of low-level wastes. The waste producers are responsible for carrying out and funding such disposals.

For high-level wastes:

- the Government takes overall responsibility for appropriate and steady implementation of the disposal programme as well as enacting any laws or policies required in this connection;
- the Power Reactor and Nuclear Fuel Development Corporation is required to conduct research and development for geological disposal and make geological environmental surveys;

- the electricity utilities are required to secure the funds for disposal and to take responsibility for the necessary research and development.

STORAGE

Spent fuel is stored in ponds at the nuclear power plants and at the reprocessing plants.

Liquid high-level wastes are stored at the Tokai reprocessing plant, awaiting the start-up of the vitrification plant. Facilities for the storage of returned reprocessing wastes and for spent fuel awaiting reprocessing are being constructed at Rokkasho-mura.

Low-level and transuranic wastes are stored at the sites where they are produced.

DISPOSAL

A shallow burial repository for low-level wastes began operation at Rokkasho-mura in 1992. Wastes are confined by a combination of engineered and natural barriers. The final planned capacity of the repository is 600 000 m^3. A repository for extremely low-level radioactive waste, mainly 2200 t of concrete waste from the dismantling of JPDR, is going through licensing procedures.

For high-level wastes, the national policy published in 1992 requires an organisation to be set up with responsibilities for site investigation, selection and characterisation and for demonstrating disposal technology at the candidate site.

Experiments have been carried out in several locations with varying geological environments. An underground laboratory is to be built at Horonobe, though this will not be the final repository site. A repository is scheduled to start operation in the 2030s, or in the mid-2040s at the latest.

KOREA

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

Nuclear energy provides 36.3% of Korea's electricity (1995), from 10 reactors with an installed capacity of 8.6 GW. Six reactors with a capacity of 5.1 GW are under construction.

Spent fuel is stored at the power stations prior to the construction of central interim storage facilities.

NATIONAL WASTE MANAGEMENT STRATEGY

Low- and medium-level wastes are to be disposed of in a rock-cavern-type of repository on a coastal area or on an island.

Spent fuel is to be stored in a central interim storage facility.

RESPONSIBILITIES

The Atomic Energy Commission (AEC) is Korea's top policy-making body on nuclear matters. The Ministry of Science and Technology (MOST) is responsible for nuclear R&D, nuclear safety, and the management of the radioactive waste fund. The Korea Institute of Nuclear Safety (KINS) technically supports MOST in licensing by performing safety assessment review and inspections on nuclear facilities. The Ministry of Trade, Industry and Energy supervises the construction and operation of nuclear power plants.

The Korea Atomic Energy Research Institute (KAERI) is assigned to work on all nuclear related R&D activities and its subsidiary, the Nuclear Environment Management Center (NEMAC), has been designated to carry out the national radioactive waste management programme.

Funding for waste management is through a levy on the electrical utility, based on the amount of electricity generated from nuclear power plants, and on other waste producers, based on waste category and volume.

STORAGE

Operational wastes are stored in surface facilities at sites of nuclear facilities.

Spent fuel is stored in pools or in dry concrete canisters at reactor sites.

The method of storage (wet or dry), the storage capacity and the target date for a central interim storage facility of spent fuel are to be reevaluated.

DISPOSAL

Guleop Island has been designated as a candidate site for disposal of low-level radioactive wastes. The site investigation activities at the island started very recently. A final decision for suitability of the repository site will be concluded by the results from the investigation.

Research is being carried out on safety assessment technologies and on structural behaviour, geological and hydrogeological characteristics related to the proposed rock cavern repository.

There have been no moves to establish disposal facilities for spent fuel, which is to be held in a central interim store.

MEXICO

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

Nuclear energy provides 3.1% of electricity in Mexico (1994), from two reactors on the same site with an installed capacity of 654 MW each. The second reactor came into operation in April 1995.

Spent fuel is being stored at the power station, pending decisions on the future development of the Mexican nuclear power industry.

NATIONAL WASTE MANAGEMENT STRATEGY

A permanent repository is to be developed for all low- and medium-level wastes, including those from medical and industrial activities.

The long-term strategy for spent fuel management remains to be decided.

RESPONSIBILITIES

The Federal Electricity Commission (CFE) is the state-owned national electricity utility and is the only entity that can utilise nuclear materials to generate nuclear power. It is responsible for managing the radioactive wastes from its operations.

The Secretariat of Energy (SE) is responsible for regulatory activities through its subsidiary body, the National Commission of Nuclear Safety and Safeguards (CNSNS).

SE is responsible for policies and contracts regarding radioactive waste management. It has delegated some of its responsibilities to CFE and the National Nuclear Research Institute (ININ).

CNSNS is a specialised technical body in charge of regulating nuclear and radiological safety, physical security and safeguards for all nuclear facilities in Mexico.

ININ and the Institute of Electrical Research (IIE) carry out nuclear research and development.

STORAGE

ININ manages an interim repository for all low- and medium-level waste produced in medical and industrial radioisotope applications. Low- and medium-level wastes from nuclear generation are stored at the reactor site pending the development of a disposal facility.

Spent fuel is stored in cooling ponds at the reactor site pending decisions about future management strategy. The pools have been re-racked to increase the original capacity, in order to accommodate all the spent fuel that the reactors will produce during their expected operating life.

DISPOSAL

Detailed studies are under way in order to determine the engineering design basis for a "triple-barrier" repository, using a French approach. This is planned to have capacity for low- and medium-level wastes generated during the operating life of at least four nuclear reactor units, and could also include the wastes from medical and industrial sources.

Decisions remain to be taken on the final disposal of spent fuel.

NETHERLANDS

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

Nuclear energy provides 5.1% of electricity in the Netherlands (1994) from two reactors with an installed capacity of 0.5 GW.

Spent fuel from the existing nuclear power plants is being reprocessed abroad, with the resulting wastes returned. For possible future nuclear power plants, the question of whether or not to reprocess has been left open.

NATIONAL WASTE MANAGEMENT STRATEGY

Government policy on radioactive waste is based on the 1984 Report on Radioactive Waste, which contains two basic starting points. The first is temporary storage of all radioactive wastes produced in the Netherlands. The second is the Government policy of research into the possibilities of the permanent disposal of such wastes. The first of these two approaches has led to the establishment of the Central Organisation for Radioactive Waste (COVRA) at Borsele; the second has led to the research programme of underground disposal. In addition to incorporating these programmes into an international framework, the government policy is also aimed at concluding international agreements governing the conditions and provisions attached to temporary storage and/or definitive disposal, wherever possible.

Government policy is to create facilities for the long-term storage of all highly toxic wastes that will allow retrieval of the wastes. All radioactive wastes are therefore to be stored centrally, for a period of between 50 and 100 years.

An important part of the Government's radioactive waste policy is the role of the international organisations. The main thrust of the activities lies in the exchange of information on, and the coordination of, national research programmes. As well as actively participating in the various consultative fora, the Netherlands, together with other countries, is also studying possibilities for developing international disposal facilities. So far, however, these initiatives have not produced any concrete results. Nevertheless, the Netherlands' participation in the various international consultative fora has made a major contribution to the development of its national policy.

RESPONSIBILITIES

The national radioactive waste company COVRA is responsible for all kinds of nuclear wastes. 90% of the shares in COVRA are held by the main waste producers, and 10% by the State. Decisions are taken on unanimity, which means that every Shareholder including the State has the right to veto the decisions due to be taken.

The Integral National Research Programme on Nuclear Waste (ILONA) was set up to carry out research on the possibilities for the permanent disposal of radioactive waste. A Programme for Disposal on Land (OPLA) was set up under ILONA in 1985 to study disposal in salt formations. The first phase of the study concluded that permanent disposal in rock salt was technically feasible and in all probability could be accomplished safely. However the results of this study did not totally cover the Government's requirement of retrievability. Although there was, from a scientific point of view, no reason not to proceed to the next phase of the OPLA programme, it was decided that first a more generic programme should be started in which, among other subjects, emphasis should be given to research on the various aspects and possibilities of retrievable storage (including the economic aspects).

STORAGE

COVRA operates a centralised treatment and storage facility for low- and medium-level radioactive waste at the industrial area Vlissingen-Oost in the south-western part of the country. Low- and medium-level waste from all producers in the country is shipped by COVRA to this facility. After treatment, the conditioned waste product is stored in storage buildings for a period of 50 to 100 years.

Storage for low- and medium-level wastes is in a building with three modules each of 5000 m^3 capacity. The building can be extended with a fourth storage module. For further expansion, four buildings with four storage modules each could be constructed on the site. The total storage capacity will then be 80 000 m^3.

In addition to these storage buildings, four other storage buildings with a total capacity of 110 000 m^3 are foreseen to store depleted uranium and solid waste materials with a relatively high concentration of natural radionuclides which are produced in the ore-processing industry.

For the handling and storage of high-level waste, mainly resulting from reprocessing of spent fuel, the construction of a naturally cooled storage vault is planned. This should be ready to receive high-level waste by the year 2000.

DISPOSAL

While the option of disposal of radioactive waste is not currently being pursued, work is continuing on a number of topics, including:

- research into retrievable disposal methods, both under and on the surface, and comparisons of these various in terms of safety and in relation to the policy criteria contained in the “isolation, control, surveillance” concept;
- updating the instruments and database developed under the OPLA programme;
- examining to what extent there may be other possibilities, in addition to long-term disposal and transmutation, for processing or binding radioactive wastes in such a way as to eliminate the risks of radiation.

SPAIN

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

Nuclear energy provides 33.8% of Spain's electricity, from nine reactors with an installed capacity of 7.4 GW (1994).

Spent fuel is stored at the power stations. Fuel from the Vandellos 1 station, now shut down, is being reprocessed abroad and the resulting high-level waste will be returned to Spain. The reprocessing option is not currently being contemplated for the current power stations, and additional storage capacity is being planned, either at the power stations or at a central site, to allow about 40 years of interim storage of spent fuel before disposal.

NATIONAL WASTE MANAGEMENT STRATEGY

Low- and medium-level wastes are being disposed of at the near-surface repository at El Cabril.

Spent fuel and vitrified high-level wastes will be disposed of deep underground.

RESPONSIBILITIES

The national radioactive waste company ENRESA is responsible for all activities related to the management of radioactive wastes, including spent fuel.

The Ministry for Industry and Energy (MIE) plays a major role in the control of nuclear activities, granting the necessary licenses and authorisations, although other ministries or competent bodies are also involved. The Nuclear Safety Council (CSN) is the competent body in matters of nuclear safety and radiological protection.

A public institution, CIEMAT, is responsible for research and development activities in the nuclear field, among others, and provides technical support for ENRESA, CSN and MIE.

The costs of waste management are financed by those responsible for producing the wastes. For nuclear power wastes, a fee is established, based on a percentage of total electricity sales. For other producers, payment is by a tariff applied when the wastes are actually removed.

STORAGE

Most low- and medium-level wastes are temporarily being stored at the sites where they arise until they are sent to the El Cabril disposal facility. Some conditioned wastes were stored in the past at a central temporary storage facility at El Cabril, in reinforced concrete bays.

Spent fuel is being stored in pools at the power station sites. Additional capacity is being provided by changing the fuel storage racks. Storage capacity may be further increased by means of metal casks or by the construction of a central interim storage facility.

DISPOSAL

A repository for low- and medium level wastes is in operation at El Cabril. The concept is based on near-surface disposal with engineered barriers. The facility consists of 28 concrete vaults, each of which will accommodate 320 concrete containers. Each container is in the form of a square concrete box with a capacity for 18 waste drums, the voids being filled with cement mortar. When each vault is filled it will be covered by a reinforced concrete slab. After the operational phase is over, the disposal structures will be covered by a long-term cover.

The siting process for the deep geological repository for spent fuel and other high-level wastes covers studies in granite, salt and clay. A final choice of the general location will be made by the year 2000. The intention is to start construction in 2015 and for the repository to be operational in 2020.

Non-site specific conceptual repository designs have been developed. In the salt concept, wastes in self-shielding casks would be placed in drifts excavated at a depth of 850 m in a bedded salt formation. In the granite concept, wastes in steel canisters, embedded in a thick layer of swelling clay, would be placed in drifts excavated at a depth of 500 m. A design for a repository in clay is under development.

SWEDEN

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

Nuclear energy provides 51% (1994) of Sweden's electricity, from 12 reactors with an installed capacity of 10 GW.

Some 140 t of spent fuel from past operations has been shipped for reprocessing abroad. All spent fuel is now stored at the power stations for about one to five years, and then transported to a central storage facility (CLAB) for storage for 30-40 years before disposal.

NATIONAL WASTE MANAGEMENT STRATEGY

Operational wastes (low- and medium-level, short-lived) are being disposed of at the final repository, SFR, at Forsmark.

Spent fuel and long-lived radioactive residues will be disposed of deep underground, after a period of interim storage.

RESPONSIBILITIES

The waste management responsibilities of the nuclear utilities are handled by their jointly owned company, the Swedish Nuclear Fuel and Waste Management Company, SKB.

The SKB programme is reviewed every three years by the Swedish Nuclear Power Inspectorate, SKI, which forwards the programme and their review report to the Government for decision.

Licenses for the construction and operation of waste management facilities including repositories are granted by the Government, on the basis of reviews and recommendations from the SKI and the Swedish Radiation Protection Institute.

Funding to cover the costs of spent fuel management is collected by SKI, based on a charge per unit of nuclear electricity produced. The dues are deposited at the National Bank of Sweden and SKB is reimbursed from this fund. Costs for the management and disposal of operating wastes are borne directly by the utilities.

STORAGE

Spent fuel is stored in pools at reactor sites for about one to five years, followed by central interim storage for 30 to 40 years. Operating wastes are disposed of as soon as possible after they are produced.

The central storage facility for spent fuel, CLAB, is located next to the Oskarshamn nuclear power station. It consists of an above-ground receiving and handling facility and an underground, man-made rock cavern, about 30 m below the surface. The spent fuel is stored under water in stainless-steel-lined concrete pools.

DISPOSAL

The final repository for low- and medium-level wastes, SFR at Forsmark is constructed in bedrock under the Baltic, with a rock cover of about 60 m. It has various caverns for different waste categories. The waste containing most of the radionuclides is disposed of in a large concrete silo in a 70-m high cylindrical rock cavern. Rock caverns 160 m long are used for the rest of the wastes. Various types of backfill, buffer and seal will be used; the most extensive being in the silo repository where the waste packages will be backfilled with concrete and the silo is surrounded by a clay barrier. When the silo is filled a concrete lid will be cast on top. The buffer will be completed with a layer of sand and bentonite clay over the lid. The space above will be backfilled with sand.

A repository for spent fuel will be constructed at a depth of about 500 m in Precambrian crystalline rock. The fuel will be encapsulated in copper canisters with an inner steel container, placed in boreholes and surrounded by highly compacted bentonite. The repository tunnels will be backfilled with a mixture of sand and bentonite or a similar mixture, and the main tunnels and shafts will be plugged.

The spent fuel elements stored in the CLAB facility will be encapsulated in canisters in a special facility before disposal. An encapsulation plant is planned to be built in connection to CLAB. The aim is to start the licensing procedure for the plant in 1997.

Geological investigations started in the mid-1970s and about 15 different study sites have since been investigated by surface, and in many cases, also borehole measurements. These investigations indicate that many sites are technically feasible for hosting a repository. Feasibility studies for a deep repository will be performed in 5-10 municipalities in Sweden followed by geological site investigations in two of these municipalities. The aim is to select one site for detailed characterisation starting a couple of years after 2000. In preparation for the site characterisation and for the repository construction SKB has constructed the Äspö Hard Rock Laboratory, located near the Oskarshamn nuclear power plant. The laboratory consists of a tunnel of 3.6 km down to a depth of 460 m, and associated facilities.

The aim of the activities performed at Äspö is to evaluate investigation methods, to demonstrate tools for design, planning and construction of a repository and to collect data for safety analyses.

The target for start of disposal of encapsulated spent fuel is 2008. The repository is planned to be commissioned in two phases with only up to 800 t (uranium weight) disposed of in the first phase. The first phase should be followed by a thorough evaluation of all pertinent experiences (including the possibility of waste retrieval) before deciding to proceed with the second phase.

SWITZERLAND

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

Nuclear energy provides 36.7% of Switzerland's electricity, from five reactors with an installed capacity of 3.1 GW (1994).

Spent fuel is reprocessed abroad, and the resulting wastes are returned to Switzerland for interim storage and disposal. The option of disposing of non-reprocessed fuel is being kept open. The minimum interim storage period for high-level waste is planned to be 40 years.

NATIONAL WASTE MANAGEMENT STRATEGY

All radioactive waste are to be disposed of in repositories in suitable geological formations. Two repository types are envisaged, one primarily for short-lived wastes and one for high-level and long-lived medium-level wastes.

RESPONSIBILITIES

The producers of radioactive wastes of all categories are responsible for their safe management.

The National Co-operative for the Disposal of Radioactive Waste, NAGRA, was formed by the electricity utilities involved in nuclear power and the Swiss Confederation, which is responsible for the wastes from medicine, industry and research. NAGRA is responsible for preparation of projects for final disposal and possible final conditioning of the wastes, as well as for the preceding controls.

For construction and operation of repositories, special companies are formed. The first of these, the Co-operative for Nuclear Waste Management, Wellenberg (GNW), was established in June 1994 to implement the low- and medium-level waste repository planned in the Canton Nidwalden in Central Switzerland.

The responsibility for spent fuel reprocessing, and transport, waste conditioning and interim storage remains with the utilities. For centralised interim storage a special company, ZWILAG, was founded to construct and operate the facilities.

The Federal Government is supported in its decisions on waste management by a number of federal agencies, other federal offices, and scientific institutions.

The costs of waste management are borne directly by the producers. The contributions from the electricity utilities at present are linked to the nuclear power production capacity; the contributions from the Swiss Confederation are calculated for a virtual "power equivalent". Project costs are paid directly by the producers; there is no State organisation for collecting and redistributing funds for repository implementation.

STORAGE

Spent fuel is stored in pools at the power stations until it is transported abroad for reprocessing. Returned reprocessing wastes will be stored in a central interim storage facility.

A project for a central facility has been submitted by ZWILAG to the Government. It is intended to use dry storage for fuel elements or high-level wastes in transport containers in a surface hall. Low- and medium-level wastes will be stored in separate surface halls or else co-located. A site has been chosen at Würenlingen and a general licence has been granted by Parliament.

Storage capacity for interim storage of spent fuel and high-level wastes will be sufficient for the current nuclear power plants.

DISPOSAL

The reference repository concept selected for short-lived low- and medium-level wastes is a mined cavern system with access through horizontal tunnels. Safety studies have confirmed the acceptability of this concept. One hundred potential sites were evaluated during 1978-81. Twenty sites were selected for additional evaluations, which were carried out in 1982-83. Subsequently, four sites were identified for detailed investigations, and Wellenberg was selected as the "preferred" site in 1993. A general licence application was submitted by GNW in June 1994. The local community at the Wellenberg site has voted in favour of the repository project. However, a referendum in June 1995 at the cantonal level led to a narrow majority (2%) of opponents to the project. The technical, legal and political ramifications of this decision are currently (1995) being reviewed by the governmental authorities and by NAGRA and GNW.

The reference design envisages wastes solidified in cement, bitumen or polymers, waste drums possibly grouted into a concrete container, backfilling of the remaining empty spaces with special concrete, concrete lining of the disposal caverns and sealing of access tunnels on final closure. The wastes may be divided into several toxicity classes, with appropriate combinations of barriers for each class.

The reference repository concept for high-level and transuranic wastes is a system of mined tunnels and silos at a depth of about 1200 m in crystalline basement rock or 500 to 800 m in clay. Vitrified high-level wastes would be surrounded by a corrosion-resistant steel canister, a layer of highly compacted bentonite clay, and, finally, the host rock and its overburden. The transuranic waste would be embedded in a leach- and dissolution-resistant solidification matrix and emplaced in a cylindrical concrete silo surrounded with special concrete. The spaces between the filled concrete silo and the rock wall of the cavern would be backfilled with bentonite. The final design will depend on the rock type and site selected. Site investigations have been concerned with regions for potential sites; the next phase of investigations involves field work in both crystalline and clay formations. In November 1994 applications for geologic investigations at two specific sites were submitted by NAGRA to the government. Repository construction, or alternatively participation in an international project, is planned for some time after 2020.

An extensive research programme has been under way at the Grimsel underground rock laboratory since 1984, involving co-operative projects with other countries since 1991.

UNITED KINGDOM

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

Nuclear energy provides 26.9 per cent of the United Kingdom's electricity, from 34 reactors with an installed capacity of 11.9 GW (1994). A new reactor with a capacity of 1.2 GW started operation in 1995.

Spent fuel is stored in ponds at power station sites; at the Wylfa station air-cooled storage is used. Spent fuel awaiting reprocessing is stored in ponds at Sellafield

NATIONAL WASTE MANAGEMENT POLICY

Solid low-level wastes are being disposed of in near-surface facilities at Drigg and Dounreay. An underground deep disposal facility for stocks and future arisings of medium-level wastes and selected low-level wastes is to be developed.

High-level (heat-generating) wastes from fuel reprocessing will be stored, normally in vitrified form, for at least 50 years. Wastes from the reprocessing of fuel from BNFL's overseas customers will be returned to the country of origin.

The final conclusions of a review of the United Kingdom radioactive waste management policy were published in a White Paper in July 1995. Existing disposal strategies for intermediate and low-level waste were confirmed. For high-level waste, the White Paper identified disposal to geological formations on land as the favoured option for the long term, once the waste has been allowed to cool, and the Government is initiating work on a research strategy for the disposal of high-level waste and spent fuel.

Wastes arising from reprocessing foreign spent fuel should continue to be returned to their country of origin, but for low-level waste and intermediate-level waste this can be achieved by substituting a radiologically equivalent amount of high-level waste in a manner which achieves broad environmental neutrality for the United Kingdom, subject to a disposal route for the substituted wastes being established.

RESPONSIBILITIES

Policy is set by the Secretaries of State for the Environment, Scotland and Wales, who may refer matters to the Radioactive Waste Management Advisory Committee for advice. The National Radiological Protection Board provides information and advice on the radiological aspects of waste management standards. Her Majesty's Inspectorate of Pollution (HMIP), or its Scottish equivalent, is the organisation having the primary responsibility for ensuring compliance with the national policy for radioactive waste management. The Health and Safety Executive (HSE) regulates nuclear safety and the accumulation of radioactive waste on nuclear licensed sites. HSE and HMIP cooperate to ensure that the national waste management policy is implemented.

The owners of spent fuel are responsible for its safe management, including whether or not to reprocess it.

The producers of radioactive wastes are responsible for their safe management, including meeting all associated costs. The industry has established UK Nirex Ltd. to develop a facility for low- and medium-level (but not high-level) wastes, and holds its ordinary shares. The Government holds one Special Share.

STORAGE AND DISPOSAL

Low-level wastes are currently stored for the minimum practical period before being disposed of.

Low-level wastes are disposed of mainly at BNFL's Drigg facility, although UKAEA disposes of low-level wastes arising at Dounreay at facilities there.

The Drigg facility near Sellafield has been the principal site for low-level waste disposal since 1959. For many years wastes were placed directly into trenches cut into a clay layer within the glacial sediments, with capping to reduce water ingress. Since 1989 compacted and grouted wastes contained in drums or boxes have been placed in concrete-lined vaults which will be capped when filled.

Medium-level wastes are currently stored, mainly at the sites of production, awaiting disposal in UK Nirex's planned deep disposal facility. HSE regulates such storage to ensure its safety. UK Nirex is currently investigating a site near to BNFL's Sellafield Works for its proposed deep disposal facility for medium- and low-level wastes. It plans to excavate a series of caverns in volcanic rock over 650 m below ground level, into which the conditioned wastes will be emplaced. Its next step is to develop a Rock Characterisation Facility in the proposed strata to demonstrate their suitability for the facility. This is currently the subject of a planning enquiry.

High-level wastes are stored before vitrification. The vitrified wastes will be stored for at least 50 years, to allow them to cool, before being disposed of in a suitable facility. Storage and vitrification are currently being carried out by BNFL in the Vitrification Plant which the Company opened in 1991.

UNITED STATES

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

Nuclear energy provides 19.6% of electricity in the U.S.A., from 109 reactors with an installed capacity of 99 GW (1994). One reactor with a capacity of 1 GW is under construction.

Spent fuel is not currently being reprocessed. Spent fuel, and the high-level wastes resulting from past reprocessing activities, will continue to be stored, at the power stations, the reprocessing plants, and possibly at central storage sites, pending the development of disposal facilities.

NATIONAL WASTE MANAGEMENT STRATEGY

Three categories of waste are defined: low-level, transuranic and high-level. Transuranic wastes are wastes contaminated with long-lived radionuclides such as uranium and plutonium. High-level wastes include spent fuel and heat-generating wastes from reprocessing.

Low-level waste disposal remains the responsibility of each State within which the waste arises. Several shallow land burial sites are currently in use.

Systems for the disposal of transuranic and high-level wastes are to be developed by the U.S. Department of Energy.

A Monitored Retrievable Storage (MRS) facility is authorised for interim storage of spent fuel, but a site remains to be identified.

RESPONSIBILITIES

The storage and disposal of most commercially generated low-level wastes is the responsibility of the States in which they are generated. Many States have formed interstate agreements in order to share disposal responsibilities. All other wastes are the responsibility of the Federal Government. The generators are responsible for the storage of commercial spent fuel and high-level wastes until the Federal Government takes title to such wastes in 1998.

The federal agencies involved include the Department of Energy (DOE), responsible for storage and disposal, the Nuclear Regulatory Commission (NRC), responsible for regulation and licensing, and the Environmental Protection Agency (EPA), responsible for protection standards.

For spent fuel and high-level wastes, the owners and generators pay the full costs of disposal, and a National Waste Fund has been set up to cover the costs of the civil waste management programme. The fund receives revenue from all those planning to use the repositories. An adjustable fee is charged to utilities, based on the amount of nuclear electricity generated. For low-level wastes, the generators provide funding from their operating budgets.

STORAGE

Commercial low-level wastes are stored on the sites where they arise until enough waste is available for a shipment to a disposal site. The failure to provide disposal capacity is increasing the need for on-site storage. Facilities in use include permanent buildings designed specifically for the extended storage of such wastes, shielded concrete storage modules or bunkers, and shielded storage casks.

Transuranic wastes are held in temporary stores pending the development of disposal sites. Storage methods include retrievable burial, below-ground bunkers, concrete caissons, ground-level concrete pads, and buildings.

Most spent fuel is stored at power station sites in pools, although as pool storage capacity limits are being reached, increased use is being made of dry storage, in concrete modules, concrete or metal casks, and modular vaults.

Several technologies are being considered for the proposed central MRS facility, including pools, dry vaults, multi-element sealed canisters in concrete modules, metal dual-purpose storage and transport casks, and concrete casks. Several of these design concepts have either been licensed by the NRC or are in the process of being licensed.

High-level wastes are being stored in liquid form at DOE facilities at Hanford, Idaho National Engineering Laboratory and Savannah River. These wastes will be vitrified in facilities now under construction and stored pending the availability of disposal facilities.

DISPOSAL

Seven shallow-land disposal facilities for commercial low-level wastes have been operated, of which five are no longer in use. They consist of excavated trenches, in some cases with a 5-m soil cover or an engineered cover such as concrete. Several alternative concepts are now being considered by the States, such as below-ground vaults and earth-mounded concrete bunkers. Future facilities are likely to incorporate engineered barriers to a greater extent than do currently operating facilities. There are currently eleven inter-State compacts, and six States have opted to go it alone. Three sites are either at the characterisation or at the licensing stage, in California, North Carolina and Texas.

The DOE has six facilities for the disposal of its low-level wastes, at Savannah River, Oak Ridge, the Nevada Test Site, Los Alamos, Idaho National Engineering Laboratory, and Hanford. Designs include shallow-burial trenches, below-ground vaults, tumuli, above-ground vaults and deep shaft burial.

A Waste Isolation Pilot Plant (WIPP) has been constructed near Carlsbad, New Mexico. WIPP is intended for the disposal of DOE-generated transuranic wastes. The wastes, contained in drums or boxes, are disposed of in a 2000-ft thick salt formation, 2150 ft below the surface, with access via four shafts. There are currently over 10 miles of tunnels constructed, but most of the repository area remains undisturbed awaiting transuranic wastes for disposal. A decision regarding WIPP's suitability as a repository will be made when evaluation of the current Test Program is completed.

Yucca Mountain, Nevada, is being characterised by DOE as a potential site for the disposal of spent fuel and high-level wastes, generated commercially and by DOE itself. Construction of an underground Exploratory Studies Facility began in 1993. The current design concept for the repository is for a number of disposal galleries accessed by two ramps and a possible shaft. In the reference design, wastes, suitably packaged, would be placed in vertical holes bored in the floors of the galleries, but other methods, such as emplacement in horizontal boreholes and within the galleries themselves, are also being considered. In the reference design, no buffer material will be used around the waste packages because the waste package is designed to be surrounded by an air gap, but alternatives using a variety of backfills are also being evaluated. If the site is found to be suitable, disposal operations are planned to begin in 2010.

Chapter 3

MANAGING RADIOACTIVE WASTES

Summary

Each category of radioactive waste is managed through a sequence of stages from initial categorisation to final disposal. The final disposal of the more radioactive and long-lived categories involves containment by multiple barriers; direct dispersal to the environment is used for low-level liquid and gaseous wastes. Both of these methods are designed to achieve the fundamental objective of radioactive waste management protection of current and future generations from unacceptable exposures to radiation. Detailed planning and control of each stage of the waste management sequence is required in order to ensure that this objective is met.

The natural radioactive gas radon is released during the mining and milling of uranium ore and uranium enrichment. Improved techniques are being applied to mining and milling tailings to reduce further the already low radiation doses that occur. The small amounts of radioactive gases produced in reactors themselves are held under pressure in delay tanks to allow decay of the shorter-lived components and filtered before release. The resulting low-level gaseous effluent is dispersed through closely monitored stacks. Techniques are available to immobilise long-lived components to make them suitable for disposal.

Slightly radioactive liquids derive from the operation of reactors and reprocessing plants. These contain traces of fission and activation products from the fuel and from the cooling ponds in which fuel is stored, and require some form of treatment before release. Four main treatment methods are being used: evaporation involving the trapping of volatile radionuclides; ion exchange which binds radionuclides to a solid adsorbent; filtration; and chemical precipitation. All four techniques concentrate the radioactivity in a solid or liquid form suitable for containment, and result in a residual low-level liquid effluent which is dispersed in accordance with site authorisations.

Slightly radioactive rubbish arises wherever radioactive materials are handled. This low-level waste is reduced in volume by compaction, incineration

or decontamination prior to disposal near the surface or deep underground. Though deep-sea disposal has been carried out successfully in the past, the majority of the signatories to the London Dumping Convention *have recently voted for its total prohibition. Near-surface disposal in trenches or increasingly in engineered facilities has been implemented for many decades in several countries, and deep disposal at depths up to hundreds of metres is being carried out or planned in a number of countries.*

Decommissioning wastes consist mainly of large quantities of slightly radioactive material, such as structural steel and concrete. Although no large nuclear power stations have yet been completely dismantled, there is extensive experience with decommissioning research and prototype reactors and other nuclear facilities. The radioactivity of a shut-down nuclear reactor falls by a factor of over 100 000 during the first 100 years after the removal of the last charge of fuel. Most nuclear utilities are therefore planning to seal their nuclear reactors securely within their concrete biological shields for a period, after which dismantling becomes much simpler. Most of the material that then results will be disposed of as low-level waste.

Medium-level wastes such as filter sludges, fuel cladding and used industrial and medical radioisotope sources may require short or very long-term isolation and are generally immobilised in cement or bitumen prior to disposal. Such wastes require sufficient shielding and strength to be of no risk in case of accident: they are therefore stored in steel drums with additional concrete for shielding. They require disposal in massive structures near the surface or 50 to 500 m underground in concrete lined caverns or existing mines, backfilled and plugged with concrete. The disposal of short-lived medium-level wastes has been implemented in several European countries. Long-lived medium-level wastes are held in stores pending the development of disposal facilities.

High-level waste is either in the form of spent fuel or concentrated waste from reprocessing. In both cases, massive shielding is needed, as is a period of cooling to allow the heat to die away: this generally takes place in cooling ponds at reactor sites or at a centralised store. Used fuel that is not to be reprocessed is encapsulated in containers designed to last for hundreds to millions of years. High-level waste from reprocessing is vitrified and sealed into stainless steel containers. Both types of high-level waste will be disposed of deep underground in stable geological formations, which are subject to detailed assessment prior to disposal. However, there are considerable technical benefits from delaying disposal for at least several decades, during which time much of the heat emission of both types of high-level waste will have died away. No country has yet implemented final disposal of high-level waste.

Safe disposal of long-lived wastes deep underground is based on containment by multiple barriers, of which the principal ones are the engineered structures of the repository itself, and the retentive properties of the mass of rock between the repository and the surface. There are many different types of geological formations that can provide the necessary protection and ensure that the radioactivity of the wastes decays to negligible levels before they reach the biosphere.

Research is continuing into waste management issues. Physical, chemical, biological and hydrogeological studies are required in order to provide a more precise quantitative understanding of the complex processes that might affect the long-term safety of waste repositories. Empirical studies of existing disposal facilities, in underground laboratories, and at naturally occurring concentrations of radioactive materials are also under way.

Principles of radioactive waste management

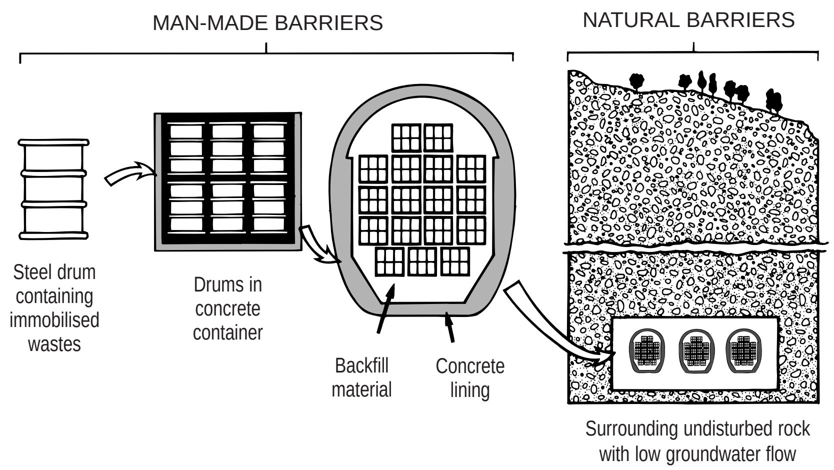
There are two ways in which the fundamental objective of radioactive waste management – the protection of current and future generations from unacceptable exposures to radiation from the wastes – can be achieved. They are:

- by *containment*, generally using a combination of man-made and natural barriers to achieve effective isolation of the wastes till their radioactivity has decayed to levels that no longer pose any unacceptable risk;
- by *dispersal*, ensuring that the wastes become so dilute in the environment that they do not present any unacceptable risk to people at any time by any pathway.

It is relatively straightforward to provide containment that will ensure the necessary level of protection in the short term, using techniques that have been developed throughout the nuclear industry and elsewhere over many decades. Complete containment in perpetuity, however, can clearly never be demonstrated. Nevertheless, there is wide scientific and technical agreement that disposal in deep stable geological formations is the best currently available option for long-lived wastes, both from the technical and from the ethical point of view, and this is the option being pursued in most countries that need to dispose of such wastes.

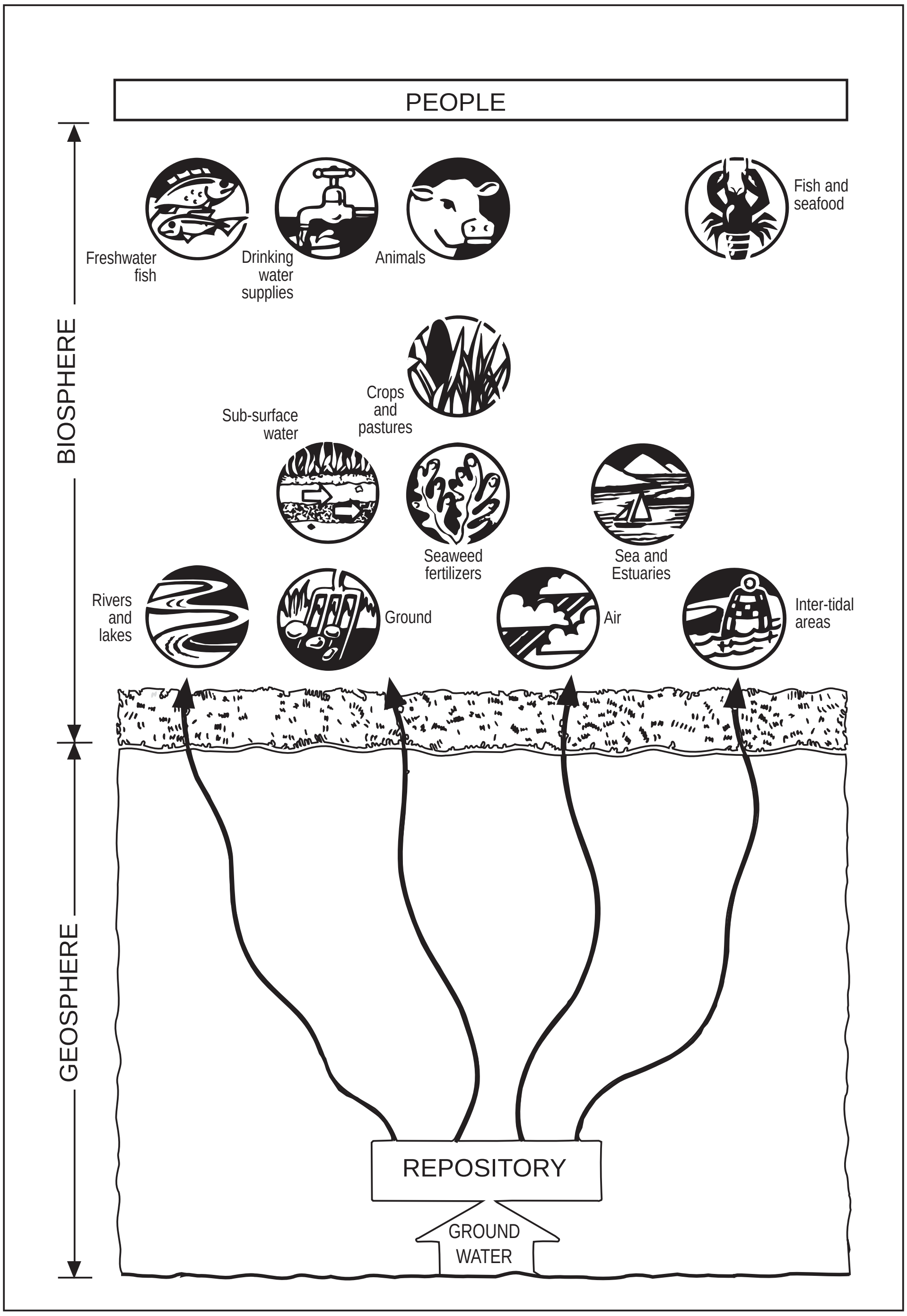
In order to establish that a deep disposal operation satisfies all the regulatory requirements, it is necessary to analyse the effectiveness of the overall containment system over the very long periods needed for all components of the waste to decay, and any pathways by which radioactive material could eventually

Containment by multiple barriers



reach the human environment. These pathways must be long, and the speed at which materials travel along them must be slow, so that the radioactivity of any residual material that may eventually reach the biosphere will have decayed to negligible levels. Inevitably, knowledge of the long-term processes involved will only be partial, so large margins of error must be allowed for to ensure that safety is achieved under all conceivable circumstances. In addition, the location of the wastes must be such as to minimise the possibility of inadvertent intrusion as a result of human activity, such as mineral exploration or extraction, which could result in unacceptably high radiation exposures to those involved. Breaching of the barriers by natural processes such as earthquakes or erosion must be made extremely unlikely, by appropriate siting and depth of disposal, since this could result in unacceptable radiation exposures to people who may be living nearby.

With the dispersal approach, the consequences in terms of radiation exposures depend both on the nature of the dispersal and on possible pathways through the environment. The effectiveness of this method can readily be assessed by a programme of environmental monitoring, since radioactivity in the environment can be detected at very low concentrations. A comprehensive monitoring scheme is normally a requirement of any authorisation to dispose of wastes by dispersal.



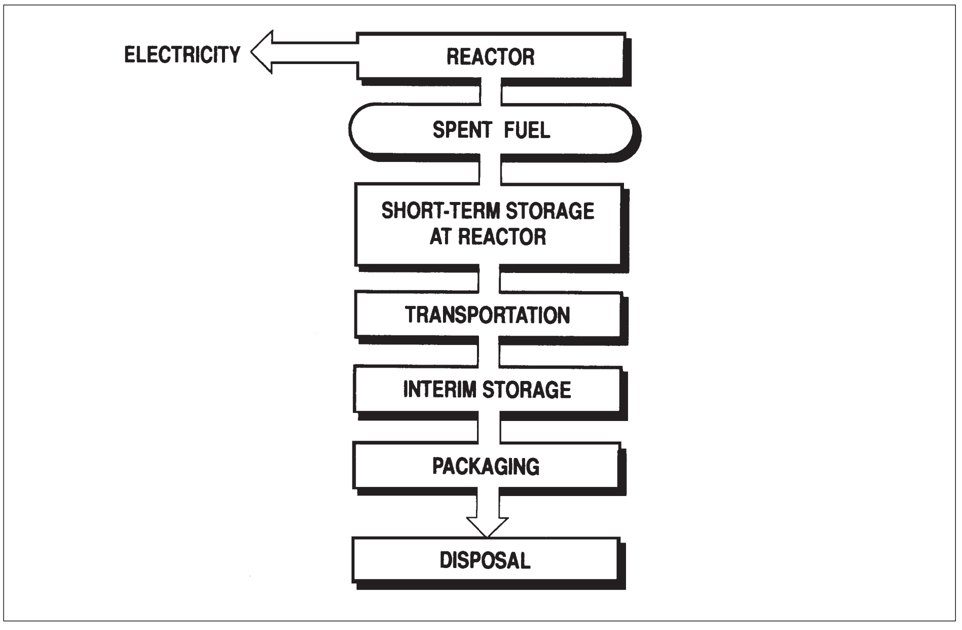
Possible pathways by which radionuclides which are dissolved and transported by groundwater can move from a deep repository through the geosphere and biosphere to people.

Some specific low-level liquid and gaseous wastes, which are long-lived, of low toxicity and readily diluted in water or air, are dealt with by the dispersal method, usually after some form of physical or chemical treatment to remove substances suitable for containment. Other wastes are all managed by the containment method, usually after solidification for wastes that are not already solid, and some form of encapsulation. Underground disposal of encapsulated radioactive waste can ensure that all but a very small minority of the long-lived radioactive substances will decay away within the confines of the repository and its surrounding rock. Any residual radioactive material reaching the surface after thousands of years would do so at concentrations which would be very small indeed compared to those of naturally radioactive minerals present in almost all rocks.

Management options for spent nuclear fuel

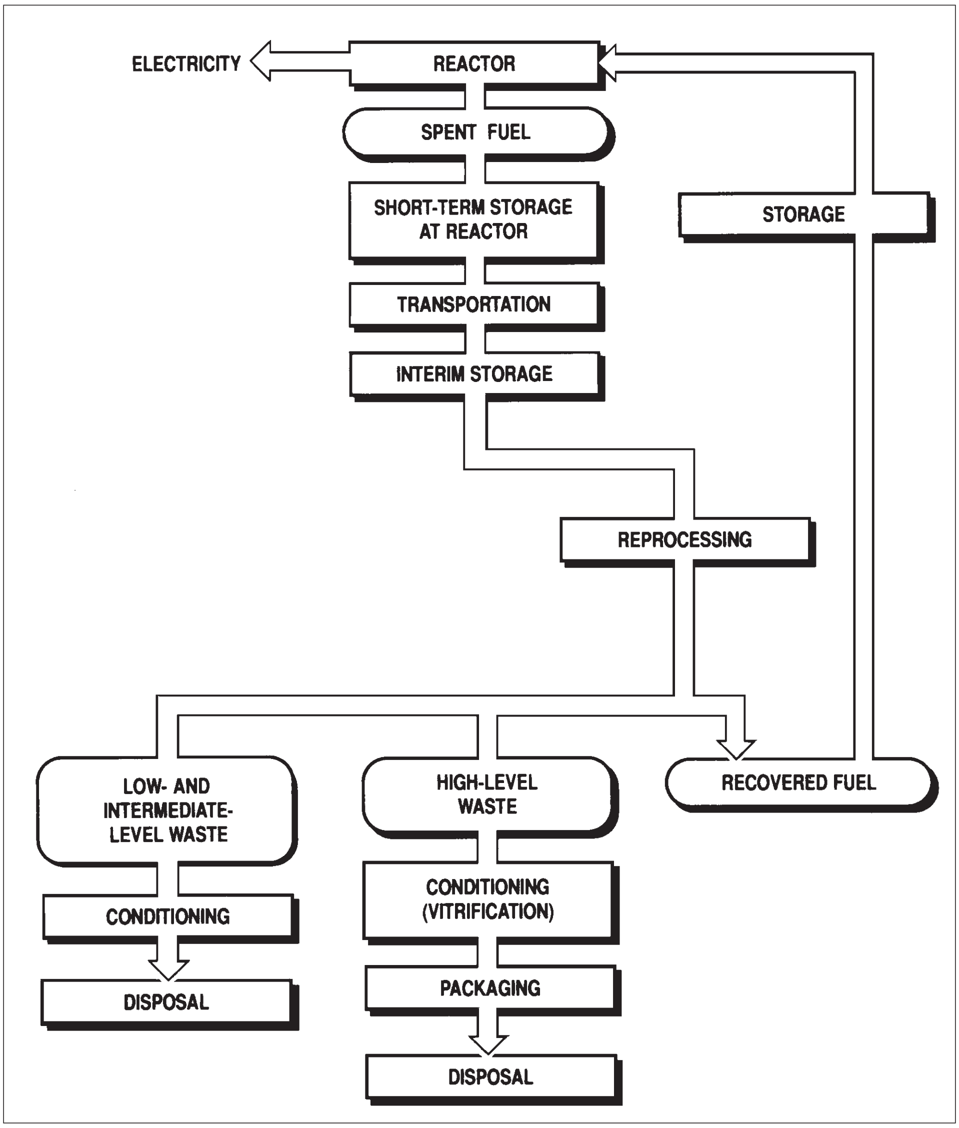
The selection of a management technique for most waste streams is based on an assessment of the cost-effectiveness of the various technical options available for meeting the regulatory requirements, including the ALARA requirement. For spent fuel, however, which contains most of the radioactivity resulting from nuclear electricity generation, the choice between the available options is more complex.

Spent fuel management – Direct disposal



There are two ways in which spent fuel may ultimately be managed: direct disposal of the spent fuel, and reprocessing of the fuel, followed by disposal of the resulting wastes. In the direct disposal route, spent fuel is stored for several decades, while much of the heat generation dies away, and then disposed of intact, suitably encapsulated, in a deep geological repository. In the reprocessing

Spent fuel management – Reprocessing and recycling



route, the spent fuel is again stored for a period, and then reprocessed to separate the waste from the reusable fuel. The resulting high-level liquid waste is solidified and stored for a further period before disposal deep underground. Reprocessing also produces additional low and medium-level wastes. Some groups reject both these options and advocate storage of the spent fuel, but since this would require future generations to maintain the stores and ensure their integrity indefinitely, it is in general not considered to be satisfactory from a long-term safety and ethical point of view. The Netherlands, however, currently has a policy of long-term storage rather than permanent disposal, essentially because the main disposal method so far studied in that country, burial in deep rock salt formations, is inconsistent with the Dutch Government's requirement that wastes should be retrievable. All other OECD countries that have long-lived radioactive wastes to deal with are currently developing or intending to develop the deep geological disposal option.

The choice between direct disposal and reprocessing depends on a number of technical, environmental, economic and strategic factors which differ from country to country. In the early days of nuclear power, reprocessing was viewed as the preferred long-term strategic option in most countries, not primarily as the best way of dealing with wastes but because it would enable the utilisation of the uranium fuel to be increased by around a hundredfold, turning uranium from a useful but limited source of energy into a virtually limitless one and reducing the need for uranium mining. Only one form of uranium is naturally fissile, that is capable of sustaining a nuclear chain reaction, and this form constitutes only a few percent of typical reactor fuel.

Plutonium, however, an activation product formed by interactions between neutrons and the much larger fraction of non-fissile uranium, is itself fissile and therefore a potential nuclear fuel. Reactors have been designed specifically to produce and use plutonium, and in this way virtually all instead of only a small fraction of the available energy of the uranium can be used. Such reactors are called "fast" reactors, because the nuclear chain reaction is maintained by fast neutrons instead of slow or "thermal" neutrons as in conventional (thermal) reactors. Many prototype fast reactors, up to commercial size, have operated for many years in several countries. In addition, a number of countries, most notably Canada and India, have examined the use of the thorium fuel cycle, which also offers the potential for a virtually unlimited supply of fission energy.

During the 1950s and 1960s, uranium resources were thought to be strictly limited and the demand for nuclear power was expected to grow rapidly, making a system that increased the utilisation of the fuel by a large amount very desirable. Fast reactors and reactors using the thorium fuel cycle were then expected to take over from once-through thermal reactors relatively rapidly as the main reactor types. But the slow-down in energy demand that resulted from the oil crises of the 1970s and 1980s also resulted in a major slow-down in nuclear programmes. In addition, major exploration programmes had resulted in the discovery of large new uranium ore deposits. While the fast reactor is still being developed under a joint European programme, as well as in Japan and in Russia, the urgent need for advanced fuel cycles has receded.

Some countries are maintaining the reprocessing option and planning to use plutonium in thermal reactors in the form of a mixture of plutonium and uranium oxides – Mixed Oxide Fuel or MOX – while others, including Canada, Spain, Sweden and the U.S.A., have abandoned reprocessing, at least for the time being. Currently, France and the U.K. have large reprocessing plants for fuel from their own reactors and from those in several other countries (including Belgium, Germany, Italy, the Netherlands, Switzerland and Japan, but Belgium and Germany are also keeping open the option of direct disposal of spent fuel), Japan has a small plant and is building a large one; there are plants in India, and there are plants in use and under construction in Russia. Most international reprocessing contracts include a clause providing for the return of the wastes, together with the recovered uranium and plutonium, to the country of origin.

Waste management systems

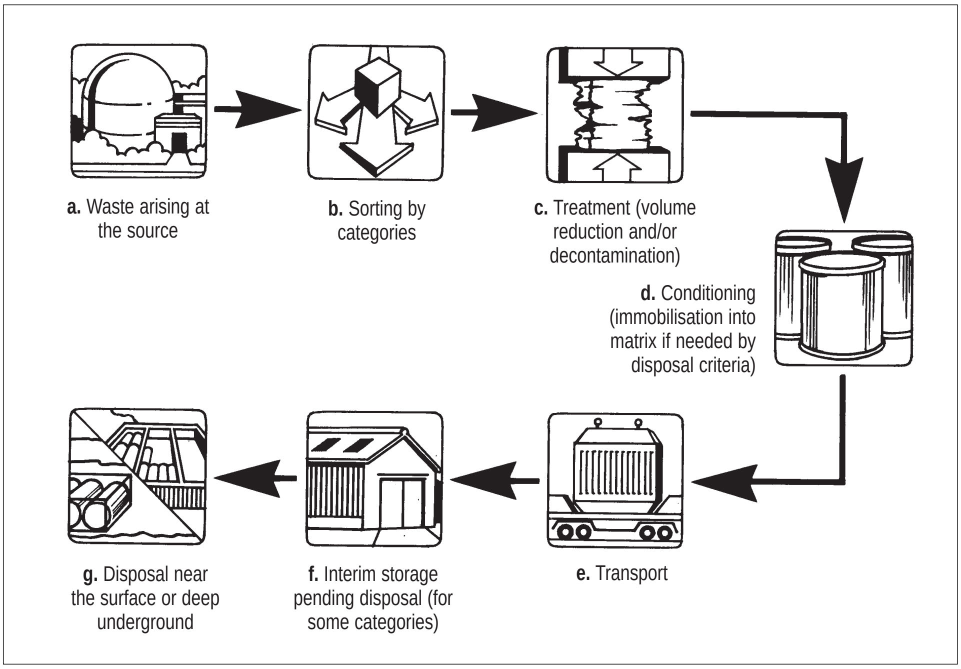
A waste management sequence (for wastes that are not dealt with by dispersal) typically includes sorting by categories, treatment (volume reduction, decontamination, incineration), conditioning (immobilisation into a matrix), transport, interim storage pending disposal, and final disposal. There are however many possible overlaps and conflicts between the requirements of these various stages. For example, a container that appears the best choice for wastes in an interim store may not be suitable for the geological environment selected for final disposal and the wastes would then have to be repackaged before disposal, which could have major cost and worker exposure implications. An integrated-systems approach is therefore needed to maximise overall safety and minimise costs.

The planning of an integrated waste management system requires information on:

- regulatory requirements;
- quantities, categories and locations of wastes and the rates at which they are produced;

- treatment and conditioning options and facilities and their location and capacities;
- optimum storage periods, for example to allow heat production to fall;
- location and capacities of stores for each category of waste;
- availability and requirements for transport;
- location, availability and characteristics of disposal sites.

Typical radioactive waste management scheme



In some cases, not all this information is available when the plan is drawn up. This is particularly true at present for the disposal of long-lived wastes where, in general, sites have not yet been selected. In such cases, where no early action is planned, all options may be kept open to allow any social and political as well as purely technical considerations to be taken into account.

The following sections of this chapter outline the management systems that have been developed and implemented or are being planned for each major waste category.

Gaseous wastes

The mining and milling of uranium ores result in the release of the radioactive gas radon, which escapes when the ore is brought to the surface and ground into fine particles. To date, mining wastes and mill tailings have tended to be kept in open, uncontained piles or behind dams or dikes with solid or water cover. While this has not resulted in significant radiation exposures of the public, a number of techniques for reducing the release of radon are available and are gradually being implemented, in accordance with the ALARA principle. These include simple capping with silt or clay, multi-layer capping with additional erosion protection, and disposal below ground level with clay capping.

Uranium enrichment (increasing the proportion of uranium-235, the fissile component of uranium, from its natural level of 0.7% to the 2% to 4% level required by most modern reactors) and fabrication into fuel elements also result in very small quantities of gaseous wastes, essentially the same as those from mining and milling, which are controlled by conventional filtration techniques.

Some radioactive gases are produced in the nuclear reactors themselves. Gaseous fission products can escape from defective fuel elements or are released when fuel is dissolved at the first stage of reprocessing. Gaseous activation products are produced in the coolant or reactor containment by neutron bombardment. Traces of radioactive dust and aerosols from various sources can become entrained in ventilation air. The main techniques for dealing with these gases are hold-up under pressure in delay tanks to allow decay of the shorter lived components before release, caustic scrubbing, and filtration. Any low-level gaseous effluent that remains is discharged to the atmosphere through a ventilation stack, which can be over 100 m high to aid dispersal, and is monitored both locally and in the surrounding environment. These techniques are effective and meet health, safety and environmental requirements, as described in Chapter 4.

Low-level liquid wastes

Some slightly radioactive liquid effluents arise from uranium mining and milling in wet areas, but the quantities and possible consequences of these, as well as the liquid effluents from enrichment and fuel fabrication, are negligible compared with the gaseous releases.

The liquid effluents from reactors and reprocessing plants can contain traces of fission and activation products from the fuel, and activated corrosion products from the cooling ponds in which spent fuel is stored. There are four main treatment methods for treating these low-level liquid wastes: evaporation, ion exchange, filtration and precipitation. All four techniques involve the removal of some or all of the radioactivity from a relatively large volume of liquid and concentrating it in solid or liquid form requiring further treatment or encapsulation before disposal. The low-level liquid effluent that remains is then discharged to lakes, rivers, estuaries or seas, where it is monitored in the discharge pipes or at the discharge point, and in the surrounding environment. The radiation doses that result from these discharges are discussed in Chapter 4.

Low-level solid wastes

Low-level solid wastes arise wherever radioactive materials are used or handled, in hospitals, laboratories and industry as well as in nuclear installations. Examples of slightly radioactive rubbish are paper towels, swabs, filters, rubber gloves, overshoes and broken glassware. Some of it may not actually be radioactive, but if it comes from an area in an installation classified as a radioactive area it is always assumed that it contains traces of radioactivity and has to be treated as radioactive waste.

Credit: ANDRA, France.

Press for compacting low-level waste.

To minimise transport requirements and save space at disposal sites, the volume of low-level waste can be reduced by compaction, incineration or decontamination. Incineration is a particularly effective way of reducing the volume of many types of low-level waste, using incinerators similar to those used for many non-radioactive wastes, with additional filtration to reduce airborne emissions.

Packaging of low-level solid wastes is generally similar to that used for many other types of wastes of insignificant hazard: steel drums, and reusable containers similar to those widely used for carrying freight by road, rail or sea. The levels of radioactivity of these types of solid wastes are so low that the protection provided by these various types of packages meets all the requirements for radiation protection during handling, transport and disposal.

Once packaged, low-level solid wastes are disposed of either near the surface or deep underground.

Near-surface disposal of low-level solid wastes, either in simple trenches or in engineered facilities, has been carried out for many decades. Simple trenches are typically about 10 m deep, 25 m wide and 100 to 200 m long. After filling, the trenches are covered by about 1 m of compacted soil. The wastes are generally untreated, except to render them non-combustible where necessary. Simple trench disposal has been used mostly in the U.S.A., the U.K. and Canada but the tendency now is to move to engineered facilities, such as concrete-lined trenches or vaults, a number of which are in operation or under construction in France, the U.K., Canada, Japan, Belgium and Spain.

Deep disposal of low-level solid wastes, at depths ranging from tens to hundreds of metres, has been carried out or is planned in a number of countries, including Finland, Germany, Sweden, Switzerland and the U.K. Facilities include disused salt and iron ore mines, and specially excavated caves and tunnels. Generally, the degree of isolation provided by such facilities is far above what is required for most low-level wastes, but their use for such wastes can sometimes be justified where the capacity can be made available at low marginal cost in a repository built for medium-level wastes.

An alternative to disposal on land, sea disposal, has in the past been used for some low-level solid wastes. Packaged wastes were disposed of in the deep oceans, the majority going to a site over 4000 m deep in the northeastern Atlantic, about 800 km off the south-western tip of the U.K. These disposals were carried out between 1949 and 1967 under the control of national authorities, and between 1967 and 1982 under NEA surveillance. About 140 000 t of packaged wastes were disposed of, cast into cement in steel drums according to internationally recommended package designs and with radioactivity limits in accordance with the definitions and recommendations for disposal to sea of radioactive wastes made by the IAEA under the *London Dumping Convention*. Other sea disposals were carried out, in particular by the U.S.A. at various locations in the Atlantic and the Pacific between 1946 and the mid-1960s, and by the former U.S.S.R. But despite the favorable outcome of extensive analyses of the safety of sea disposal, the majority of the signatories to the *London Dumping Convention* voted in November 1993 for the total prohibition of this practice.

Decommissioning wastes

All nuclear installations must be safely decommissioned after the end of their economic lives. The type of waste that results depends on the type of facility being decommissioned. Nuclear reactors give rise mainly to low-level wastes, some of which, for example steam generators, can be of considerable size. The wastes from the decommissioning of some fuel cycle facilities, for example reprocessing plants, can contain long-lived radionuclides that require long-term isolation.

The management requirements for reactor decommissioning wastes depend critically on the timing of the decommissioning process. While it would be technically possible to dismantle a nuclear power station soon after shutdown, this would be difficult and expensive because of the high levels of radiation emitted by some structural components. The radioactivity of a shut-down nuclear reactor falls by a factor of over 100 000 during the first 100 years after final shutdown. Some nuclear utilities are therefore planning to seal their nuclear reactors securely within their concrete biological shields for such a period, after which dismantling becomes much simpler.

Decommissioning of reactors is therefore normally defined according to three stages. During Stage 1 the fuel is removed; this removes 99.99% of the radioactivity. Stage 2 involves the dismantling of plant and structures other than the reactor itself and its surrounding biological shield, which is then totally sealed. This is followed by a period of surveillance. Stage 3 consists of complete dismantling and site clearance and restoration. The resulting waste is mostly steel and concrete, some of which has to be dealt with as low-level waste and some of which contains so little radioactivity that it can be classified as very low-level waste or exempt waste, and therefore not subject to specific radioactive waste management regulations.

Schematic stages of decommissioning

Operating reactor

Stage 1

Stage 2

Stage 3

Decommissioning is normally carried out in three stages. During Stage 1 the fuel is removed; this removes 99.99% of the radioactivity. Stage 2 involves dismantling plant and structures outside the biological shield, which is then sealed. This is followed by a period of surveillance. Stage 3 consists of complete dismantling and site clearance and restoration.

The decommissioning of fuel cycle plant mainly involves the decontamination of surfaces, usually by remote-handling techniques to protect workers. Unlike the situation with nuclear reactors, there is generally no advantage in delaying the operation. Decontamination results in a small volume of concentrated radioactivity, which has to be dealt with as low or medium-level waste, and the cleaned structures and components are either disposed of as low-level waste or as very low-level or exempt waste, or, in some cases, recycled or reused.

Although no large nuclear power stations have yet been completely dismantled, there is extensive experience with decommissioning research, test and prototype reactors, reprocessing plants, fuel fabrication plants and radioisotope facilities. Many of these projects have been carried out as part of international co-operative programmes under NEA auspices.

Medium-level wastes

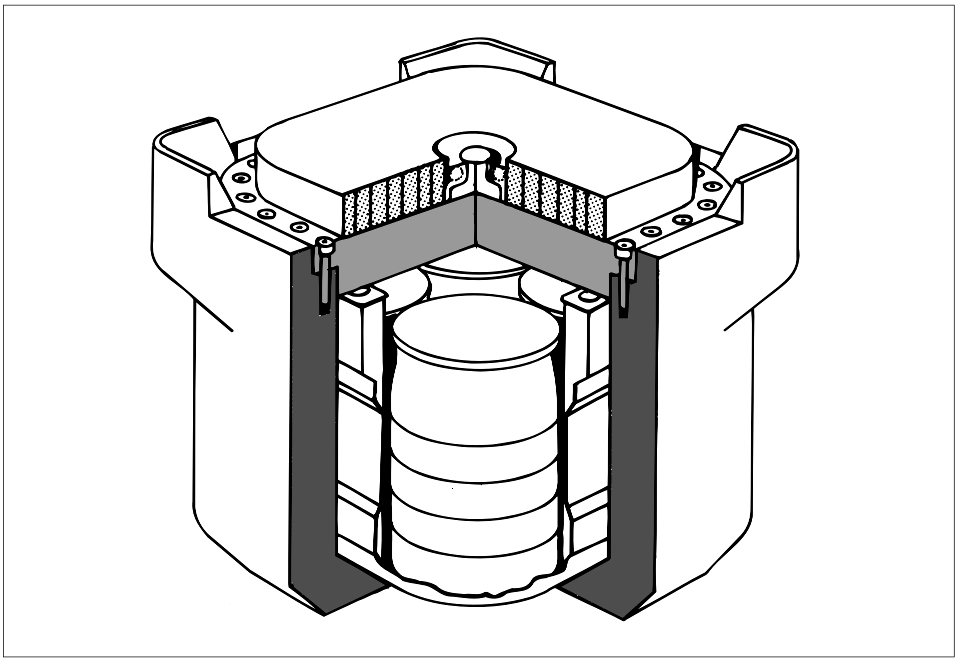
Pre-disposal operations

Medium-level wastes require special precautions during handling to limit radiation exposures. Some (the alpha wastes) need long-term isolation because of the long-lived radionuclides that they contain. Medium-level wastes can arise in a number of different forms, some wet, some dry. They include ion-exchange resins, filter sludges, precipitates, evaporator concentrates, incinerator ash, and fuel cladding.

To minimise radiation doses and the release of radioactivity during handling, transport, storage and after disposal, the main pre-disposal operations for medium-level wastes are generally immobilisation and packaging. The main immobilisation techniques are incorporation into cements, bitumens or polymers, the choice depending on the characteristics of the waste and the requirements of the disposal repository. Cement is the most common material; it is cheap, stable to radiation, has good impact and fire resistance, and provides radiation shielding. Bitumens and polymers are lighter than cement and have the advantage of being more compatible with some waste forms. However, they have less strength, fire resistance and radiation stability, and provide less radiation shielding.

The waste packaging must, together with the waste form itself, provide enough shielding to protect workers and the public, and be robust enough to contain the wastes in any conceivable accident as well as during normal handling and transport. A typical medium-level waste package will consist of one or several steel drums containing cemented waste within a reusable shielded transport container. Some large items, such as some decommissioning wastes,

Design of transport container for medium-level waste; each container holds four 500-litre drums



Credit: U.K. Nirex Ltd.

may be packed into large containers with concrete walls, which will be disposed of as a single unit rather than being reusable. Where possible, the package is designed to be ready for disposal and so long-term corrosion factors will influence the container choice.

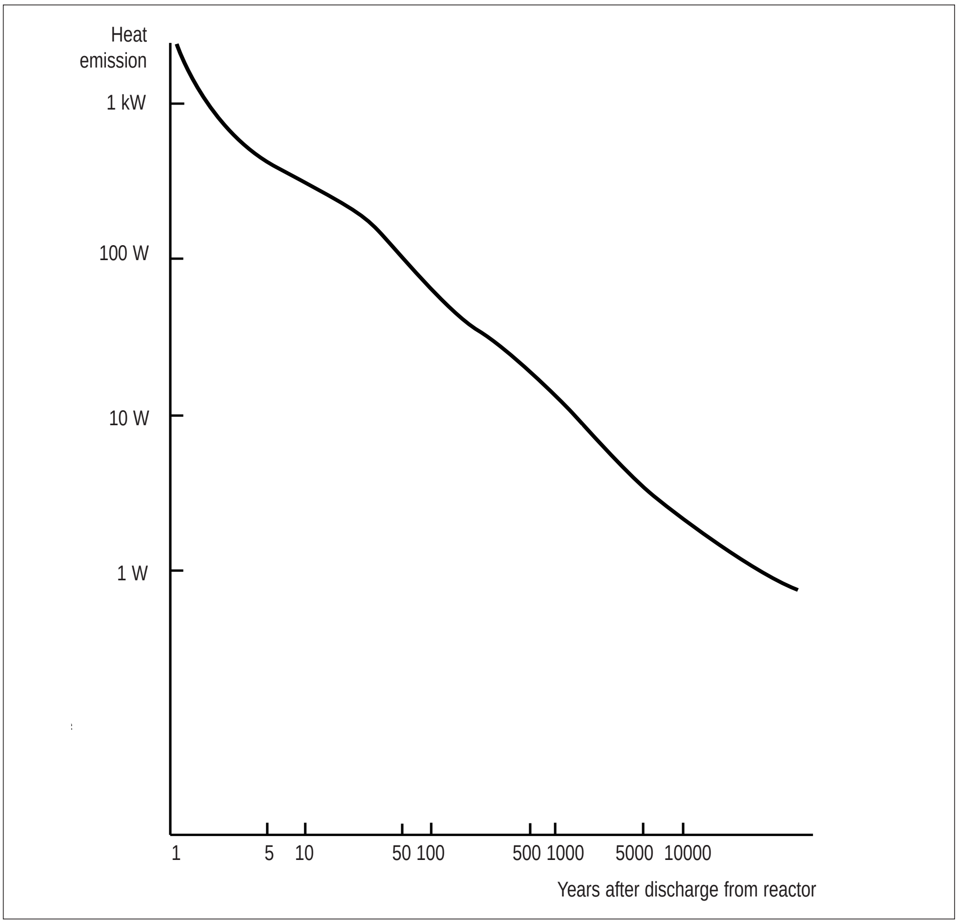
Pending the availability of deep disposal sites, most medium-level wastes are currently stored in simple buildings, with limitations on access, and continuous monitoring to confirm the integrity of the packaging.

High-level wastes

Pre-disposal operations for the direct disposal route

Pre-disposal operations for spent fuel intended for direct disposal consists of two stages: storage and encapsulation. For most reactor types, spent fuel will be kept in stores for a period of several decades, to allow the heat generation to die away. A newly discharged fuel element, from a pressurised-water reactor, for example, is so radioactive that it gives out several hundred kilowatts (kW) of

Decay of heat emission from a PWR spent fuel assembly



heat. This falls by about a factor of 20 during the first month after discharge. After one year it emits about 5 kW, after five years about 1 kW, and after 30 to 50 years the heat emission falls to negligible levels. For most reactor types, spent fuel is stored in cooling facilities, generally within the reactor building, for a period of about two years, in some cases for much longer. Storage is almost always under water, in ponds typically about 10 m deep, with massive reinforced concrete walls, the water providing both cooling and shielding.

All countries that intend to dispose of spent fuel directly envisage a further period of several decades of pre-disposal storage, either at surface level at the reactors or at surface or underground level at centralised stores. At the Swedish CLAB facility next to the Oskarshamn nuclear power station, for example, the

Credit: SKB, Sweden.

The CLAB facility, in Sweden, for the storage of spent fuel elements.

cooling ponds are in an underground cavern 120 m long, 21 m wide and 27 m high, the roof of which is 30 m below the surface. Stores at reactors are designed to take all the fuel used during the life of the reactor, or smaller amounts if centralised storage is also used, while centralised stores are designed to take all the fuel from many reactors and tend to be larger, the principal difference between the two.

Used fuel stored under water usually has direct contact between the water and the fuel cladding material and further encapsulation may be needed before disposal deep underground. The encapsulation is designed to prevent groundwater from reaching the fuel for periods from hundreds to millions of years, depending on the overall disposal concept being used. A number of different encapsulation materials (titanium alloys, copper, stainless steel, etc.) and designs have been studied and tested. For example, the Swedish approach uses a composite copper-steel cylinder with a life expectancy in the conditions expected in a deep underground repository which may be up to a few million years.

The alternative to water cooled storage is dry storage, generally using the natural convection of air for cooling. Operational experience of such stores has been acquired in a number of countries, including Canada, Korea and the U.S.A. In one design, the fuel is stored in large concrete vaults within a concrete building. In another the fuel is stored in individual casks, consisting of massive sealed steel vessels with concrete overpacks, cooled by the flow of air over the outside. An advantage of the cask method is that a single unit can be used both for storage and for transport, whereas with the vault method, special transport containers are needed to move the fuel from the store to the disposal site.

Pre-disposal operations for the reprocessing route

The first stages of the reprocessing route are the same as for the direct disposal route, that is a period of storage to allow the most intense heat production to die away. Cooling takes place first at the reactor site and then continues in storage ponds after transportation to the reprocessing plant in massive shielded containers.

Reprocessing involves stripping off the Zircaloy or stainless steel cladding that surrounds the fuel, chopping up the fuel, dissolving it in concentrated acid, and subjecting the resulting liquid to a series of chemical extractions to separate the unused uranium and the plutonium. The main waste stream is the high-level waste and contains over 99% of the non-gaseous fission and activation products in the original spent fuel.

The high-level liquid waste resulting from reprocessing spent fuel is concentrated by evaporation and stored in double-walled stainless steel tanks, surrounded by concrete shielding which is itself partially steel-lined, and cooled by multiple independent cooling coils immersed in the liquid through which water is pumped. The spaces between the layers of containment are continuously monitored, and spare tanks are always available should a problem develop at a tank requiring transfer of the contents. The maximum heat generation when a tank is filled with waste direct from reprocessing is about 1 MW, falling as the radioactivity and heat production decay. In practice, however, tanks contain a mixture of newly reprocessed and older material so the average heat generation is lower. Fission products carried by off-gases and vapours are removed by electrostatic precipitators.

While high-level liquid wastes have been stored in this way for over 30 years without serious problems, storage in liquid form has always been seen as a temporary stage; turning the waste into a solid clearly reduces the potential

Credit: COGEMA, France.

Interim storage area for vitrified high-activity waste at Marcoule (France).

for the escape of radioactivity and is more suitable for prolonged storage, transport and disposal. To address this issue, a number of solidification processes have been developed, including vitrification, synthetic minerals and ceramics. The long-term properties of the various materials are similar, but vitrification offers several operational advantages and has been implemented in France and the U.K.

In a vitrification plant, liquid waste is transferred by shielded pipeline from the storage tanks into a calciner where it is heated to dryness, leaving a fine powder. This is mixed with crushed glass in a glass-making furnace where molten glass is produced. The glass, incorporating the waste, is then poured into stainless steel containers about 0.4 m in diameter and 1.3 m high, and a stainless steel lid is then welded on. Each contains about 360 kg of vitrified waste.

The vitrified blocks in their stainless steel containers are transferred by shielded handling flasks to a store, consisting of a concrete structure which contains a number of vertical storage tubes, each designed to hold 10 containers.

Each tube is surrounded by an outer tube through which air passes. The heat generated by the waste induces an upward flow of air through the outer tube which cools the container and its contents. This method of cooling requires very little maintenance and does not depend on air circulating pumps for safe operation. The cooling air is monitored before discharge to the atmosphere. Temporary storage is envisaged for a period of at least 50 years after vitrification.

Disposal of medium and high-level wastes

Some short-lived medium-level wastes are disposed of in engineered near-surface facilities. At the Centre de la Manche and Centre de l'Aube sites in France, for example, the packaged wastes are placed in deep trenches or pits lined with concrete and then completely surrounded by more concrete, forming a massive reinforced monolith. Further packages of waste are stacked on top of the monoliths, surrounded by backfilling material, and finally covered with a thick layer of impermeable clay, and then topsoil and vegetation, forming a tumulus. The structures are surrounded by a water catchment system designed to collect the rainwater flowing over the clay layer. The water and the surroundings are constantly monitored.

Credit: ENRESA, Spain.

Aerial view of the repository for low- and intermediate-level radioactive waste at El Cabril (Spain).

Some disposals of short-lived medium-level waste have also been carried out in deep salt mines in Germany, and some were dropped on to the floor of the deep Atlantic, together with low-level wastes, before the 1983 moratorium on this operation.

A facility for the disposal of the short-lived medium-level wastes from the Swedish nuclear power programme has been constructed and is being used at Forsmark. The repository is situated in the bedrock under the Baltic Sea, with a rock cover of about 60 m. It consists of various storage chambers with different barriers, depending on the waste to be disposed of. About 40% of the wastes, by volume, contain most of the radioactivity (90%), and these wastes will be placed in large concrete silos situated in 70-m high cylindrical rock caverns. Rock caverns 160 m long will be used for the less radioactive wastes. A similar repository is in operation at Olkiluoto in Finland.

While repositories such as those at Centre de la Manche and Forsmark can fully satisfy the safety requirements for the disposal of short-lived wastes, disposal in deep stable geological formations is widely accepted as the most practicable method of achieving the objectives of radioactive waste management for wastes containing long-lived radionuclides, that is most medium and all high-level wastes. Given that a repository is constructed in a suitable geological formation and properly sealed, the only way in which radionuclides can reach the biosphere is by dissolution of the waste and transport in groundwater. The first requirement, then, is to identify a site with a stable geological formation of large enough volume, through which groundwater flow is slow, and where the transit time for groundwater to reach the surface is long.

Geological formations

The main types of geological formation that have been studied for the isolation of long-lived wastes are salt, sedimentary formations such as clay and shale, crystalline formations such as granite and gneiss, and volcanic formations such as basalt and tuff.

Salt formations are many millions of years old, and, since salt dissolves easily in water, their very existence indicates that there has been little flow of water for very long periods. Salt creeps under pressure, so any fissures tend to be self-sealing. The formations are mechanically strong, so the construction of large caverns and tunnels without roof supports is straightforward.

The main advantages of formations such as clays and shales is their ability to retain many radionuclides through a process called adsorption – the same process is used in a water softener to remove salts of calcium or magnesium from hard water. Clays are particularly attractive from this point of view, and many important radionuclides move through clay up to 1 million times more slowly than the groundwater in which they are dissolved as a result of adsorption on the surfaces of the clay particles. The rate of water movement through these formations can be very slow, and virtually zero in plastic clays. However, even in clays and shales, fracture zones can occur and, as with hard rocks, these can be areas of faster water flow.

Crystalline rocks in the unfissured state have very low permeability to water flow. In addition, they are quite good adsorbers, and have good structural and chemical stability. While formations tend to be highly fissured near the surface, and considerable water movement can occur through these networks, fissures generally decrease with depth. A major requirement of the site assessment process in such rocks is to explore and understand the water flow processes within and around the repository area.

Basalt has low permeability and moisture content and is very hard and strong. Tuff can be of two types: high density, when it has a low porosity and moisture content, or low density, when it is a good adsorber of many important radionuclides.

Siting

In addition to choosing a rock type with appropriate intrinsic properties, a repository should be sited in an area of low seismic activity. In the very long term, erosion, including glaciation, could result in uncovering of the wastes; this will influence decisions about the depth at which the repository is constructed. Factors such as the absence of potentially exploitable mineral or fossil fuel resources and reasonable accessibility for transport are also important in repository siting.

Assessment and design

Once a suitable rock formation has been identified, a detailed assessment and design process is needed to establish that a repository can be constructed and that all the regulatory requirements can be satisfied. A number of different repository designs have been developed. The design details depend on the type of waste to be disposed of, the rock type, and the local geology and hydrology.

Most designs for long-lived medium-level wastes consist of a series of large caverns or silos, excavated at depths of several hundred metres. In some cases, it is proposed to use or extend existing mines, some at depths of over

1,000 m. In a typical design, packaged wastes are transported from a surface reception area into underground concrete-lined caverns where they are stacked and surrounded by a backfilling of concrete or bentonite clay, the entire operation being carried out remotely to minimise worker exposures. When the repository is full, the entrance tunnels will be plugged with concrete.

The general approach to deep disposal of spent fuel and vitrified high-level waste is similar to that for medium-level wastes. The encapsulated fuel or vitrified blocks would be placed in boreholes drilled in the floors of mined tunnels or in the tunnels themselves. The waste containers would be surrounded by a backfill material, probably a form of cement or bentonite clay, and the tunnels themselves would be similarly backfilled. This is the approach being developed in most countries. A series of tunnels would be serviced by one or several shafts, which would be finally sealed when the repository was full. Most designs envisage a repository at a depth of between 500 and 1,000 m, depending upon local geological structures, because this reduces the risk of inadvertent human intrusion to a very low level and provides a long groundwater pathway back to the surface.

Conceptual repository designs have been developed in many countries, including Belgium, Canada, Germany, Japan, the Netherlands, Switzerland, Sweden, the U.K. and the U.S.A., and have been applied to all the types of host geological formations which are currently considered promising. Experimental and development projects are being carried out in a number of underground laboratories in several countries, many involving multi-national teams. Most countries are now at the stage of seeking and selecting suitable sites, although this process has frequently been delayed by public concern and political opposition. Repository construction in several countries is planned to start during the early decades of the next century, as some wastes approach the end of their 50 year or so interim storage period.

Three other approaches to the final disposal of high-level wastes have also been considered: extra-terrestrial disposal, ice-sheet disposal and seabed disposal.

Extra-terrestrial disposal would require the use of highly reliable launchers as well as the development of a high-integrity capsule that would survive a catastrophic failure of the space-flight system. Even if the necessary level of safety could be achieved, the cost is likely to be prohibitive in the foreseeable future and this option is not being pursued.

Disposal in ice sheets or glaciers would theoretically offer a high degree of geographical and long-term environmental isolation, but uncertainties about the long-term behaviour of ice formations give rise to serious doubts about the practicality of this approach.

Radioactive Waste Disposal
Underground Research Facilities

Country	Location	Facility	Geology and Depth	Dates
Belgium	Mol/Dessel	HADES Underground Research Laboratory	Clay 230 m	Started 1983
Canada	Lac du Bonnet, Manitoba	Underground Research Laboratory	Granite 240-420 m	Excavation started 1984
Germany	Konrad	Research in former iron-ore mine	Jurassic strata overlaid with clay 800-1300 m	Investigations started 1976
	Asse former salt mine	Research in < 1000 m	Salt dome started 1986	Operational repository 1967-1978
	Gorleben	Research in salt formation	Salt dome overlaid by gypsum rock < 900 m	Shaft sinking started 1986
	Morsleben	Research in former salt mine	Salt dome < 525 m	Safety-related investigations during 1960s
Japan	Horonobe	Deep Underground Research Facility	Sedimentary rock < 1000 m	Under planning
Sweden	Äspö	Hard Rock Laboratory	Granite < 460 m	Excavation started 1990
	Stripa	NEA underground research project in former iron-ore mine	Granite < 400 m	1980-1992
Switzerland	Grimsel	Underground Rock Laboratory	Crystalline bedrock 1 km inside a mountain underlying 450 m of rock	Started 1984
United Kingdom	Sellafield	Rock Characterisation Facility	Tuff 920 m	Planning application submitted 1994
United States	Yucca Mountain, Nevada	Exploratory Study Facility	Tuff ± 300 m	Excavation started 1993

Seabed disposal has been the subject of a number of national and international studies, including some under the aegis of the NEA. Possibilities include emplacement in deep-ocean sediments, on the ocean floor, in sub-sediment base rock, and in deep-ocean trenches.

The preferred option that has so far emerged from these studies is disposal in deep-ocean sediments, either by free-fall penetrators or in drilled boreholes. There are very large areas of suitable sediments free of seismic or tectonic activity. A number of questions remain to be answered about the long-term effects of heat and radiation on the sediments. However, the main problem about pursuing this option is political opposition to the disposal of wastes of any kind into the rocks beneath international waters.

Timing of disposal

It is technically possible to dispose of spent fuel and vitrified high-level waste immediately after treatment and encapsulation. Excessive temperature rises in the surroundings can be prevented by suitable repository design. There are, however, considerable technical advantages in allowing a period of several decades of cooling before disposal: repository designs can be simpler and the amount of excavation can be reduced, resulting in significant cost savings. These technical advantages, combined with the availability of adequate storage facilities, have resulted in all countries pursuing a policy of delayed disposal for these categories of waste, typically with delay periods of 30 to 50 years.This has the added benefit of allowing more time for site selection and safety assessment, for obtaining the necessary political and public approvals, for further research and development to increase confidence in the safety assessments, and for further exploration of any promising alternative approaches.

Research and development

The waste management techniques described in the previous sections are based on the very substantial amount of information available as a result of national and international research and development programmes over many decades, including many under NEA auspices. The structure and contents of the R&D programmes concerning waste management by containment are based on the multi-barrier concept in which the engineered structures of the repository (sometimes called the near field), the surrounding geological formations (the geosphere) and processes in the biosphere all contribute to meeting the safety criteria. The main aim is to develop a quantitative understanding of the complex physical, chemical, biological and hydrogeological processes that might affect the safety of a waste repository over the very long periods needed for some components of the waste to decay.

The results of these programmes have confirmed the practicability of waste disposal in ways that meet the necessary standards and pose only negligible risks now or at any future time. Where waste disposals have been carried out, either by dispersal or containment, detailed environmental monitoring has confirmed the absence of any unacceptable consequences. For most waste categories, however, particularly those with long-lived components, disposals have yet to be implemented and the current research programmes are concerned with establishing the safety case for specific repository designs at specific sites. To this end, the three main areas of research are: the performance of the engineered structures immediately surrounding the wastes, the performance of the geological barrier between the repository and the biosphere, and processes in the biosphere.

Research on the so-called engineered barriers, the waste form itself and its immediate surrounding structures, covers work on physical processes such as corrosion in the conditions expected in an underground repository, on chemical and microbiological processes and the way they influence the solubility and adsorption of radionuclides, and on the generation and migration of gas produced by corrosion and biological processes.

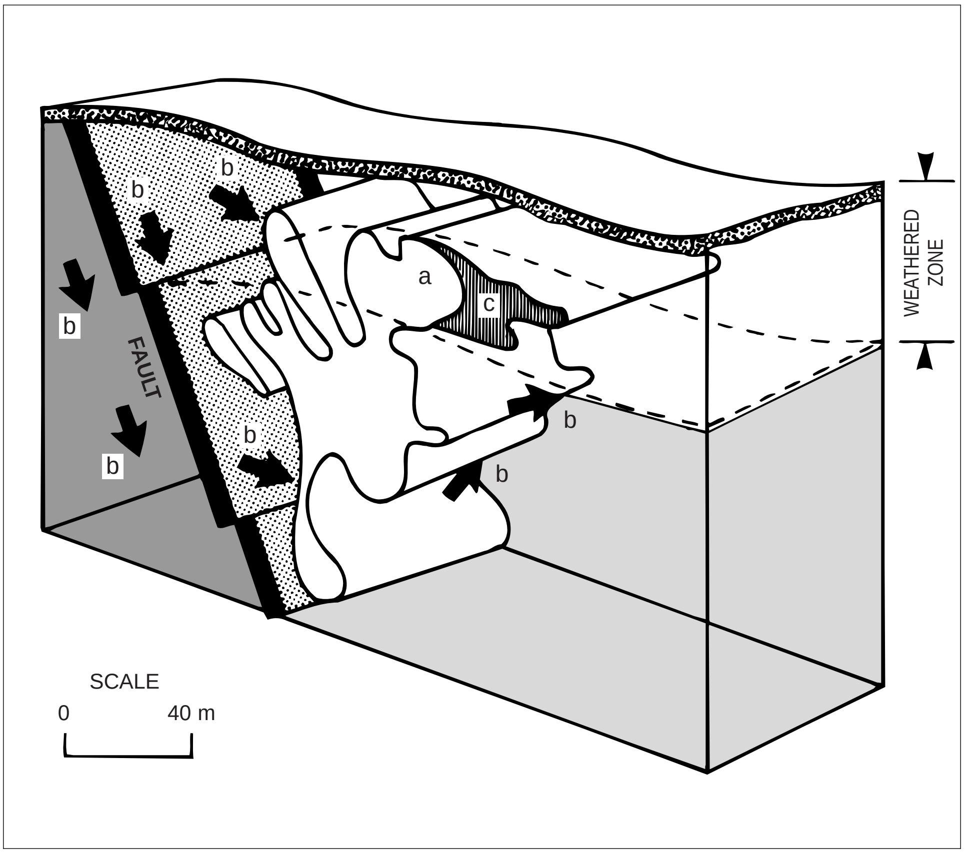
Research on the geological barriers covers the patterns and rates of groundwater flow, the migration of radionuclides carried by the groundwater, including adsorption on rock surfaces and diffusion through the near-stagnant water trapped in the pores of the rocks, and the migration of gases.

Biosphere research covers the processes that transport any residual radionuclides that eventually reach the surface through the biosphere to people and other life forms. These processes have been extensively studied in the context of discharges of radioactive effluents from nuclear installations (the dispersal method of waste management) as well as in studies of fallout from atmospheric nuclear weapons tests and natural radioactivity, principally radon and its daughter decay products. Research also covers possible long-term changes in the biosphere, for example as a result of climate change.

A useful additional source of information has been the study of natural phenomena such as radioactive ore bodies. There are many examples of rich uranium ores located in common geological formations through which groundwater flow is relatively rapid, such as the one at Alligator Rivers in

Australia, the site of an NEA joint R&D project. Movement of uranium and its decay products, many of which are similar to or identical with components of radioactive wastes, has been studied using a series of boreholes. It was found that in the weathered layers near the surface, radionuclides had moved only a few tens of metres away from the ore body in millions of years. No detectable movement had occurred in undisturbed deeper layers. A particularly important series of studies has been carried out at the natural nuclear reactors at Oklo in Gabon, where spontaneous nuclear fission processes continued over several hundred thousand years, creating several tonnes of radioactive wastes. Detailed measurements have shown that most of these materials, particularly the long-lived products, have remained close to where they were formed some 1800 million years ago.

Koongarra ore body, Alligator Rivers, Australia



A rich uranium body (a) has groundwater flewing through it (b). In the weathered zone near the surface, radionuclides have moved only a few tens of metres away from the ore body in millions of years (c). No detectable movement has occurred in the undisturbed deeper layers.

Partitioning and transmutation

While these research programmes, and the safety assessments described in the next chapter, suggest that there are unlikely to be any insuperable technical problems that will prevent the safe disposal of all types of wastes using currently available techniques, an additional approach is also being investigated as a long-term possibility. The process is known as partitioning and transmutation, and involves two stages. The first is to separate the long-lived radionuclides, mainly the alpha-emitting activation products, from the generally shorter-lived fission products at the time of reprocessing. The second is to transmute the separated radionuclides by converting them into shorter-lived fission products by neutron bombardment in a nuclear reactor or accelerator, in exactly the way uranium and plutonium are converted into fission products in conventional reactors. The potential advantage of this approach is that it reduces in principle the need to provide very long-term isolation of the wastes. However, complete conversion would require many successive stages of reprocessing and transmutation, which would in turn give rise to other types of risks, and further work is needed to establish whether the process is justified in terms of overall safety and economics.

Chapter 4

SAFETY ASSESSMENT

Summary

The objective of a safety assessment is to demonstrate that a specific radioactive waste management operation at a specific site will satisfy the relevant safety requirements under all conceivable future circumstances.

Assessment of the overall safety of the disposal system draws together analyses of the various stages of the process, and of the various pathways by which radioactivity may reach people. Such assessment provides an indication of the total radiation exposure to individuals and to populations resulting from the implementation of the particular disposal system being considered.

A wide range of assessments has now been carried out for all categories of radioactive waste. These have indicated total exposures well within regulatory limits and far below natural exposures from uranium in rocks.

Safety assessment methodologies have recently been reviewed and a Collective Opinion, adopted within the framework of the Nuclear Energy Agency, reflects the broad international consensus that we now have the means for thorough and satisfactory assessment of proposed sites.

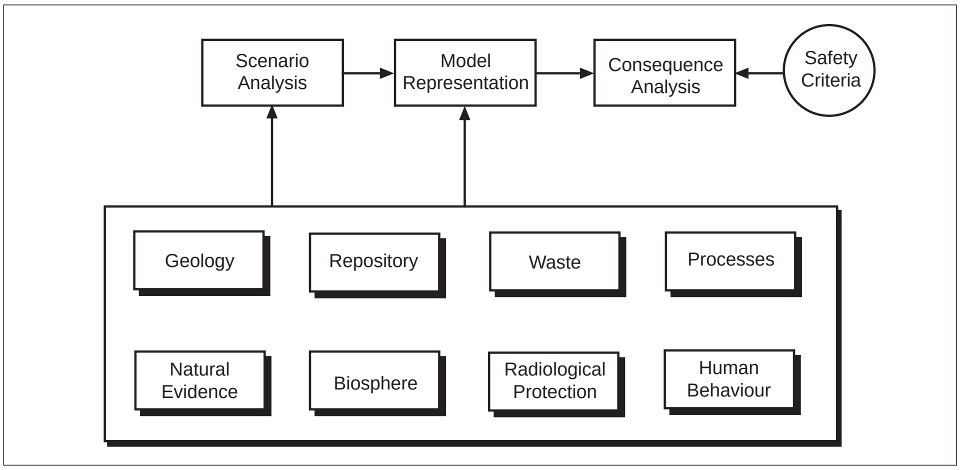
Assessment methods

The objective of a safety assessment is to demonstrate that a specific radioactive waste management operation at a specific site will satisfy the relevant safety requirements under all conceivable future circumstances.

Some stages of waste management can be assessed by means of practical tests and measurements similar to those used in other parts of the nuclear industry and elsewhere. For example, the safety of the transport containers for spent fuel has been demonstrated by a series of tests to confirm their resistance to collision, immersion in water, and fire. The safety of a discharge of a radioactive effluent to a river or the sea can be confirmed by a detailed environmental monitoring programme in the years following the discharge.

Other stages can be assessed on the basis of past experience with similar activities in other areas, an example of which is the use of stainless steel tanks for containing corrosive liquids.

But there are some stages that cannot be assessed in these ways because of the long time-scales involved. Their safety assessment has to be based on observations and experiments that can be carried out in a reasonably short time, typically months or years, combined with predictions of what is likely to happen in the future, based on a detailed understanding of all the processes involved. Such assessments make extensive use of scenarios describing the broad range of possible future situations and conditions to be considered, and use mathematical models to describe the system being assessed. Valuable additional and confirmatory information can sometimes be obtained from studies of natural analogues which have spanned relevant time-scales.The disposal of long-lived radioactive waste is a prime but not a unique example of activities needing such assessment; other examples include the disposal of some chemical wastes which retain their toxicity for ever, and the emission of some pollutants, such as greenhouse gases, which can have long-term effects on the environment or the climate.



Integrated safety assessments of a disposal system are based upon extensive and systematic use of information from many scientific and technical areas.

Pathway assessment

The “multi-barrier” approach relies on the performance of the engineered structures of the repository itself and on processes in the geosphere and the biosphere, all of which act to retard radioactive materials, allowing them to decay, and to reduce their concentration. Assessment of the effectiveness of a waste disposal concept has to consider all the possible ways (pathways) by which radionuclides could move from the repository to people. The most significant pathway is dissolution and transport by groundwater; this is called the normal pathway. Some material could be transported by gases produced by the corrosion of steel and the breakdown of biological material that may be present in the waste; this is called the gaseous pathway. In addition to the groundwater and gaseous pathways, there is the possibility that the barriers may be breached by human intrusion, for example while drilling for minerals, or by natural processes such as rock movements due to earthquakes.

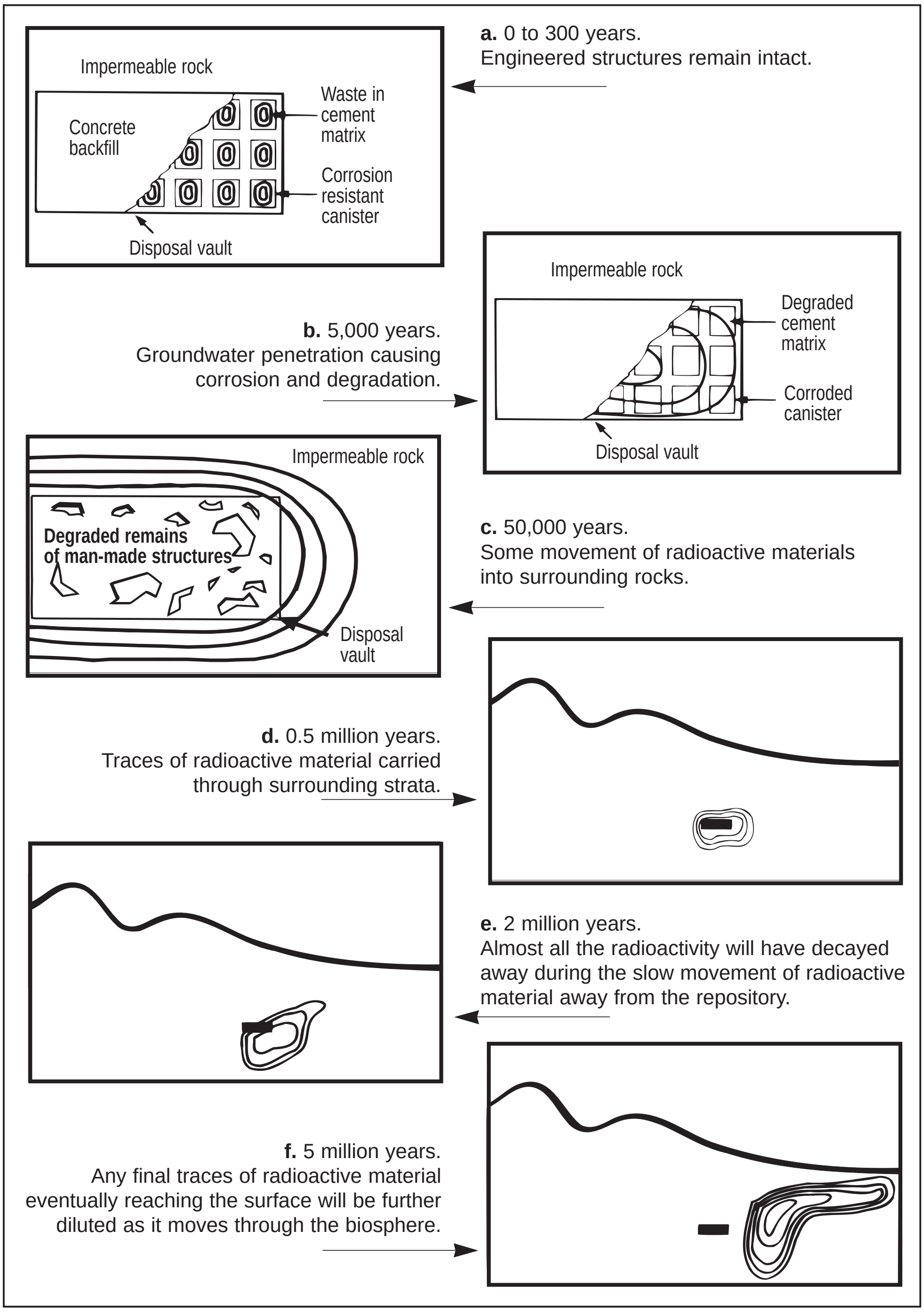
Groundwater and gaseous pathways are assessed by the use of mathematical models of the various processes involved, using general data from laboratory and field research programmes and specific information on the form and content of the wastes and packaging, on the design features of the repository, and on the properties of the site. The outcome of the assessment is a prediction of the long-term radiological consequences of the disposal in terms of radiation doses to individuals or groups of people assumed to be living in the vicinity at some time in the distant future. There are inevitably a number of uncertainties in such assessments, due to inadequate or incomplete data or insufficiently detailed understanding of the various processes involved, and an important part of the assessment process is an analysis of such uncertainties, to ensure that no combination of circumstances would lead to the safety criteria not being satisfied.

Human and natural intrusion pathways are assessed by considering possible ways in which the barriers could be breached and the consequences of each. For example, the probability of exploratory drilling for minerals penetrating a repository depends on the nature of the host rock formations and on the geometry and location of the repository. The consequences depend on drilling techniques, on the way drill cores are handled, and on the way drilling spoil is disposed of. Natural intrusion is assessed by considering past geological and climatic behaviour. But if the repository is deep enough and sited in an area with no exploitable natural resources, the risk from intrusion of any kind becomes extremely small.

System assessment

Assessment of the overall safety of the disposal system draws together the analyses of the various possible pathways, including possible interactions between them. For the normal scenario, which is dominated by groundwater transport, the first stage is to calculate the flow of groundwater around and into

Typical result of modelling of long-term movement of radioactive material through geosphere



a. 0 to 300 years.
Engineered structures remain intact.

b. 5,000 years.
Groundwater penetration causing corrosion and degradation.

c. 50,000 years.
Some movement of radioactive materials into surrounding rocks.

d. 0.5 million years.
Traces of radioactive material carried through surrounding strata.

e. 2 million years.
Almost all the radioactivity will have decayed away during the slow movement of radioactive material away from the repository.

f. 5 million years.
Any final traces of radioactive material eventually reaching the surface will be further diluted as it moves through the biosphere.

the repository. Secondly, the rate of degradation of the physical containment, the dissolution of the radionuclides and their adsorption on the structural materials of the repository, mainly concrete, are calculated, providing the source term, that is the rate at which radionuclides are carried away from the repository and into the geosphere. The third stage is to calculate the movement of radionuclides through the geosphere, using detailed calculations of the groundwater paths and flow rates and information on the various radionuclide retardation mechanisms such as adsorption on rock surfaces. This provides the input to the biosphere. Finally, calculations follow the movement of radionuclides through soils, surface waters, the atmosphere, plants and animals, enabling the estimation of radiation doses to people from inhalation or ingestion or from external exposure.

There are two ways in which the uncertainties in the data and the models are dealt with, deterministic and probabilistic. In the deterministic approach, the movement of radionuclides through each barrier is calculated using a single value of each of the various controlling parameters. The output of the calculation is a single curve showing the radiation dose to a person or group of people living near the repository as a function of time. Sensitivity studies are then carried out using ranges of values of the various parameters, to show how different assumptions affect the outcome. In the probabilistic approach, the calculations are made a large number of times, generally with the help of large computers, using values of the parameters that are not fixed but selected at random from specified ranges of possibility, according to assumed probability distributions. The output is then a series of curves showing possible consequences, with additional information about the probability of each particular consequence occurring. This is a common method of analysing complex systems whose behaviour is governed by a large number of parameters. In practice, both methods would be used to give the greatest possible confidence in the final result.

Further confidence in the assessments can be gained by applying similar methods to the behaviour of natural analogues of waste disposal systems, as described in the previous chapter, and to archeological finds such as copper, iron, concrete and glass artifacts. There is a large body of evidence showing that such materials can survive for very long periods without significant degradation in a wide range of environments.

Assessment results

Extensive measurements and environmental monitoring and analysis, carried out both by those responsible for waste management and by regulatory and other national organisations, have provided detailed information about the consequences, in terms of concentrations of radionuclides in the environment and doses to people, of all the stages of waste management that have so far been implemented. In most cases, a complete assessment also involves calculations of future doses, for example from the global circulation of any dispersed radionuclides. Environmental monitoring also provides base-line data against which future operations can be judged. The results are widely published, and are regularly reviewed by national and international agencies. Assessments of stages still to be implemented, particularly of deep disposals of long-lived wastes, range from generic assessments based on representative geological and hydrogeological data to site specific assessments based on detailed local information. The results of these various types of assessments are summarised in the following paragraphs.

Gaseous wastes

The main factors that govern the release of radon gas from uranium mining and milling are the type of mine and the design of the tailings cover. For example, the rate of release from tailings placed below ground level with a 3-m clay-shale capping is over a million times less than that from a bare tailings pile, because radon has a short half-life. Releases can continue over a very long period, so it is possible that large numbers of people can be exposed. The actual doses to individuals, however, are extremely small, a minute fraction of annual doses received from natural sources, which are themselves dominated by radon escaping from the ground. A more likely source of exposure is inadvertent intrusion or misuse of tailings, for example as building material or for road foundations.

Doses to local and regional populations from gases released from reactors and reprocessing plants are extremely small, as with mining and milling wastes. In addition, some gaseous wastes can become globally dispersed, giving doses to very large numbers of people over very long periods. The corresponding individual doses, however, are imperceptibly small.

Low-level liquid wastes

Discharges of liquid effluents from reactors can be to rivers, lakes or seas. The two major reprocessing plants, La Hague and Sellafield, discharge to the sea. Discharges from these two plants are now similar, although discharges from Sellafield were substantially higher during the 1970s. The resulting radiation doses, both from reactors and from reprocessing plants, are spread over large numbers of people, and average individual doses are very small. Some individuals, however, receive somewhat higher doses, for example a small group (about 10) consumers of locally caught seafoods in the Sellafield area. Even these people, however, receive annual doses from this source that are less than one-tenth of the annual doses they receive from natural sources.

Low-level solid wastes

A number of national and international assessments of the dispersal of low-level solid wastes in the deep oceans were carried out during the 1980s. The results of these showed that, even using pessimistic assumptions, the maximum doses that would result at any time in the future would be extremely low – a maximum individual annual dose 10 000 times less than the average annual dose from natural sources. For example, a study published by the NEA in 1985 concluded that, even if the disposal rate were increased to 10 times that of past operations, the radiological impact would remain negligible, and another published in 1986 by the U.K. Department of the Environment concluded that dropping low-level waste packages on to the bed of the deep ocean would be the preferred option over all other disposal options from the point of view of overall radiological impact for a number of waste categories. These and similar assessments appear to have had no effect on the political acceptability of this option (see p. 45-46).

Near-surface disposal facilities for low-level solid wastes are likely to be subject to a period of control, typically up to 300 years, which should ensure no major human intrusion such as building. Monitoring during that period would enable any release of radionuclides into groundwater to be detected and remedial action taken. Assessment of the overall performance of the containment system over longer periods is based on detailed information on the design and content of the facility and on the local hydrogeology. Models have been developed to describe the movement of radionuclides through the environment and their subsequent uptake by crops, animals and people, and have been validated and confirmed by laboratory and field experiments. Assessments using these models indicate that maximum doses to individuals at any time in the future are likely to be extremely small, typically less than one-thousandth of the regulatory limit.

Medium-level solid wastes

Assessment of the safety of the disposal of short-lived medium-level wastes in engineered trenches is similar to that for low-level wastes, taking appropriate account of the additional containment provided for such wastes, provided that early inadvertent human intrusion is prevented by a period of institutional control. The assessed doses from such disposals are almost entirely from the long-lived radionuclide carbon-14 and are spread over about 10 000 years, with extremely small individual doses over that period. The short-lived radionuclides decay away completely either within the repository structure or in its immediate surroundings, and the long-lived radionuclides other than carbon-14 contribute doses that are between 1000 and 10 million times lower than those from carbon-14.

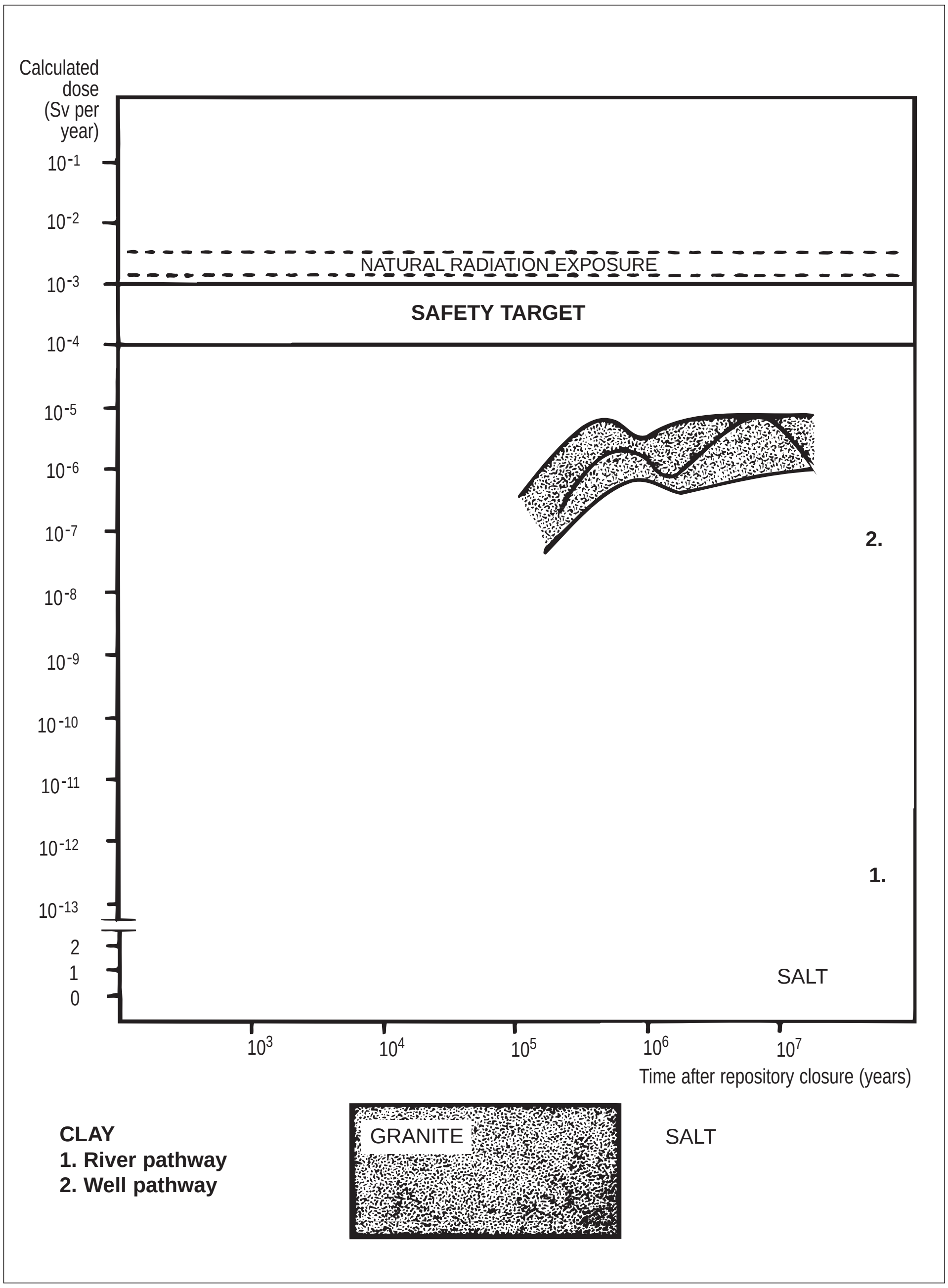
Several assessments of the safety of deep disposal of medium-level wastes have been carried out. At the Swedish Forsmark repository, a facility for medium and low-level wastes built in the bedrock under the Baltic sea about 1 km from the shore and with a rock cover of about 60 m, the maximum dose expected is 1000 times below the design goal, corresponding to an annual dose over 10 000 times less than the average annual dose from natural sources. In an alternative scenario, which assumes that land uplift in the area continues at today's rate and results in the sea bed of the Baltic in the area becoming dry land after about 2500 years, doses would still be 10 times below the design goal. Assessments for the similar repository at Olkiluoto in Finland give similar results, while assessments for disposals at considerably greater depth, for example in the Konrad iron-ore mine and in salt domes in Germany, also indicate doses well below the regulatory limits, typically occurring hundreds of thousands of years in the future.

High-level wastes

A number of assessments of the safety of deep disposal of both types of high-level wastes, encapsulated spent fuel and vitrified high-level wastes, have been carried out. One of the earliest was the first Swedish KBS study on vitrified high-level waste, published in 1978, followed by a second on spent fuel encapsulated in a copper canister. Both studies were for disposal in Swedish bedrock. The second assessment, of the approach currently proposed for the Swedish nuclear programme, indicated maximum annual doses to individuals between 1000 and 10 000 times less than average annual doses from natural sources, occurring in about 1 million years.

Other assessments have been carried out in Canada, Finland, Japan, Switzerland, the U.S.A. and a number of EC countries. The EC PAGIS project (Performance Assessment of Geological Isolation Systems) assessed the safety of disposals of vitrified high-level wastes at a series of specific sites, representing geological formations common in Europe, as well as disposal in sub-sea sediments. The assessment used both the deterministic and the probabilistic techniques. The most important result was that for all options at all sites and all scenarios, radiation doses were essentially zero for about a 100 000 years following closure of the repositories.

This result was not affected by the range of parameters used, which covered a wide range of probabilities. Some radiation doses could be expected thereafter, with the details and the timing depending on the particular conditions and assumptions. Although the uncertainties in the long-term calculations were larger than for the first 100 000 years, in no case did the estimated doses exceed a small fraction of the regulatory levels.



Credit: CEC.

Summary of some of the results from the PAGIS study. Calculated radiation doses are essentially zero for about 100 000 years following closure. Peak doses are calculated to be reached only after some millions of years. Dose rate levels, including consideration of uncertainties, are well below the safety target levels that have been set and small fractions of those due to natural background radiation.

Thus the wide range of assessments that have now been carried out for all categories of radioactive wastes and for a wide range of disposal options, all indicate that it should be possible to satisfy fully all the regulatory requirements, in some cases by a large margin. In several countries, current programmes are now concentrating on establishing the safety case for specific disposal systems at specific sites, with some further generic work aimed at reducing uncertainties and increasing confidence in the validity of the mathematical models.

Collective Opinions

Safety assessment methods

In 1991, the Radioactive Waste Management Committee (RWMC) of the NEA and the International Radioactive Waste Management Advisory Committee of the IAEA reviewed existing methodologies for safety assessment and the practical experience gained from the wide range of assessments carried out by many national and international bodies.

The review concluded that assessment methods had reached an advanced state and, when based on geological and other input data from specific sites of interest, were capable of providing risk estimates which could be used to take reliable decisions on the siting and design of a repository. International comparisons of results from test cases are being carried out to confirm that the various national computer codes work in the way that was intended and that, when supplied with specific input data, they generate similar predictions for key outputs such as the rate and direction of groundwater flow over long future time-scales.

The review resulted in the publication of a Collective Opinion, entitled *Disposal of Radioactive Waste: Can Long-term Safety Be Achieved?*, with the objective of publicising the wide international consensus which exists among experts regarding the availability of methods to assess the long-term safety of radioactive waste disposal. Endorsed by experts from the Community Plan of Action in the Field of Radioactive Waste Management of the CEC, the Collective Opinion reflects the fact that there is now wide agreement on the engineering, physical and chemical principles of the design of a repository. It registers real progress in setting up, testing and improving the conceptual framework and the technical tools necessary for long-term safety assessments. Assessments of this kind have never before been attempted for any human activity. The very low risk targets set by the regulatory bodies and the very long periods into the future over which these targets must be met set completely new standards of detailed knowledge of risk, which will doubtless be followed by other industries in time.

The fact that scientists from the many countries which subscribe to the Collective Opinion agree that the methodology and technical tools now exist for carrying out a thorough long-term radiological risk assessment of a chosen site, may help to give confidence to members of the general public who have concerns about the safety of repositories. It should also be helpful to government bodies and waste management organisations with responsibilities for managing radioactive wastes.

Geological disposal

Furthering its reflection on the management of long-lived radioactive waste, the RWMC of the NEA pointed out the importance of environmental and ethical requirements with regard to the final disposal of these wastes in deep geological formations.

In light of the growing concern for environmental protection as well as "sustainable development", the Committee organised a workshop in September 1994 to discuss the concept of deep geological disposal as a safe and passive solution which would neither depend on the stability of the institutions nor on the future level of development of society. The workshop specifically addressed the issue of potential risks and constraints to future generations in the context of considerations of equity and fairness within and between generations.

From those discussions attended by various waste management professionals in the field of research, licensing and operation, was generated a second Collective Opinion entitled *The Environmental and Ethical Basis of Geological Disposal* (see p. 74-75). The consensus reached derived from a purely scientific approach, free from any political or economical considerations prevailing in certain countries. It is essentially based on the principle that liability for waste management rests with the producer of the waste, who should provide the proper resources for their management in a way that does not impose more risk or burden on future generations than on the current one. With that in mind, the experts confirmed that "after consideration of the [current] options for achieving the required degree of isolation of these wastes from the biosphere, geological disposal is currently the most favoured strategy". They believed that the concept did not "require deliberate provision for retrieval of wastes", but that it should not be impossible to do so after closure of the repository, albeit at a cost. They proposed that the concept be implemented "through an incremental process over several decades" that would allow scientific advances to be taken into account, and not preclude other options to be developed eventually. Finally, they maintained that the process should "allow consultation with interested parties, including the public, at all stages".

THE RWMC COLLECTIVE OPINION

A Consensus Statement on the Environmental and Ethical Basis of the Geological Disposal of Long-lived Radioactive Waste

As part of its continuing review of the general situation in the field of radioactive waste management, and with particular reference to the extensive discussions at the recent NEA Workshop on Environmental and Ethical Aspects of Radioactive Waste Disposal [Paris, 1-2 September 1994], the RWMC reassessed the basis for the geological disposal strategy from an environmental and ethical perspective at its Special Session in March 1995. In particular, the RWMC focused its attention on fairness and equity considerations:

- between generations (*intergenerational equity*), concerning the responsibilities of current generations who might be leaving potential risks and burdens to future generations; and
- within contemporary generations (*intragenerational equity*), concerning the balance of resource allocation and the involvement of various sections of contemporary society in a fair and open decision-making process related to the waste management solutions to be implemented.

After a careful review of the environmental and ethical issues, as presented later and discussed in detail in the proceedings of the NEA Workshop, the members of the NEA Radioactive Waste Management Committee:

- consider that the ethical principles of intergenerational and intragenerational equity must be taken into account in assessing the acceptability of strategies for the long-term management of radioactive wastes;
- consider that from an ethical standpoint, including long-term safety considerations, our responsibilities to future generations are better discharged by a strategy of final disposal than by reliance on stores which require surveillance, bequeath long-term responsibilities of care, and may in due course be neglected by future societies whose structural stability should not be presumed;
- note that, after consideration of the options for achieving the required degree of isolation of such wastes from the biosphere, geological disposal is currently the most favoured strategy;

- believe that the strategy of geological disposal of long-lived radioactive wastes:
  - takes intergenerational equity issues into account, notably by applying the same standards of risk in the far future as it does to the present, and by limiting the liabilities bequeathed to future generations; and
  - takes intragenerational equity issues into account, notably by proposing implementation through an incremental process over several decades, considering the results of scientific progress; this process will allow consultation with interested parties, including the public, at all stages;
- note that the geological disposal concept does not require deliberate provision for retrieval of wastes from the repository, but that even after closure it would not be impossible to retrieve the wastes, albeit at a cost;
- caution that, in pursuing the reduction of risk from a geological disposal strategy for radioactive wastes, current generations should keep in perspective the resource deployment in other areas where there is potential for greater reduction of risks to humans or the environment, and consider whether resources may be used more effectively elsewhere;

Keeping these considerations in mind, the Committee members:

- confirm that the geological disposal strategy can be designed and implemented in a manner that is sensitive and responsive to fundamental ethical and environmental considerations;
- conclude that it is justified, both environmentally and ethically, to continue development of geological repositories for those long-lived radioactive wastes which should be isolated from the biosphere for more than a few hundred years; and
- conclude that stepwise implementation of plans for geological disposal leaves open the possibility of adaptation, in the light of scientific progress and social acceptability, over several decades, and does not exclude the possibility that other options could be developed at a later stage.

Chapter 5

FINANCING RADIOACTIVE WASTE MANAGEMENT

Summary

The cost of radioactive waste management is high, in the order of billions of dollars. This cost is, however, only a few percent of the value of the electricity production that has given rise to the waste. Costs are dominated by the management of the high-level wastes.

Most countries seek to finance costs on the principle of "polluter pays". This is relatively easy to achieve for short-term operations, which can be financed directly from operating income. Longer-term operations require special funding provisions that allow for the longer period between waste generation and disposal, as well as taking into account the uncertainties and the precise nature and timing of the activities concerned.

The overall funding of waste management activities is likely to involve a combination of several financing methods – direct contributions, payments to specialised waste management bodies, loans, and the establishment of funds to cover longer-term commitments.

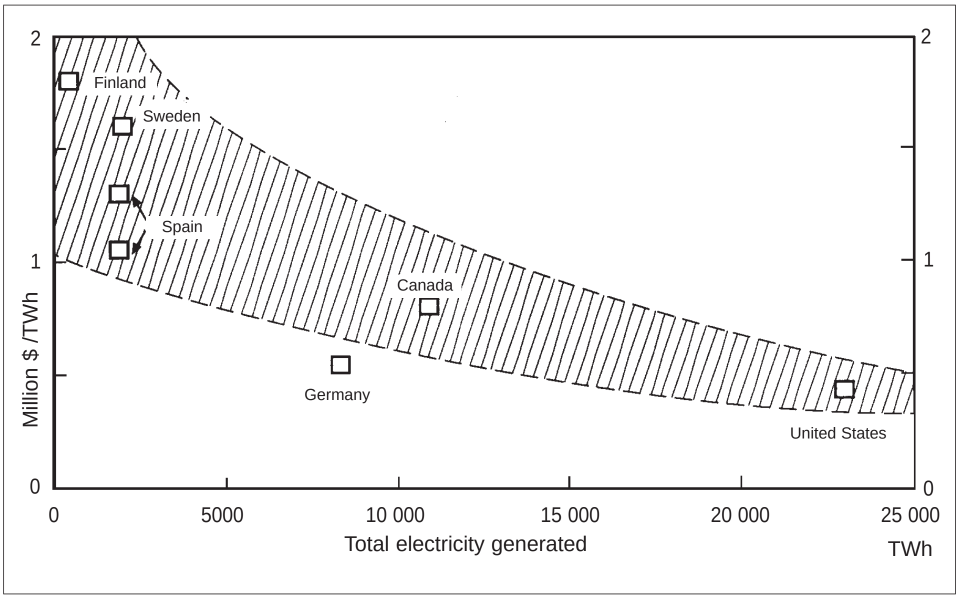
What is the cost?

Radioactive waste management costs are commonly perceived as being very high. While absolute costs, for example of a typical deep underground repository with an operational life of around 50 years, are indeed likely to be high, of the order of billions of dollars, this must be seen in the context of the value of the electricity production that has given rise to the wastes, typically several hundred billion dollars. In general, waste management costs will probably be of the order of a few percent of the total generation cost of nuclear electricity.

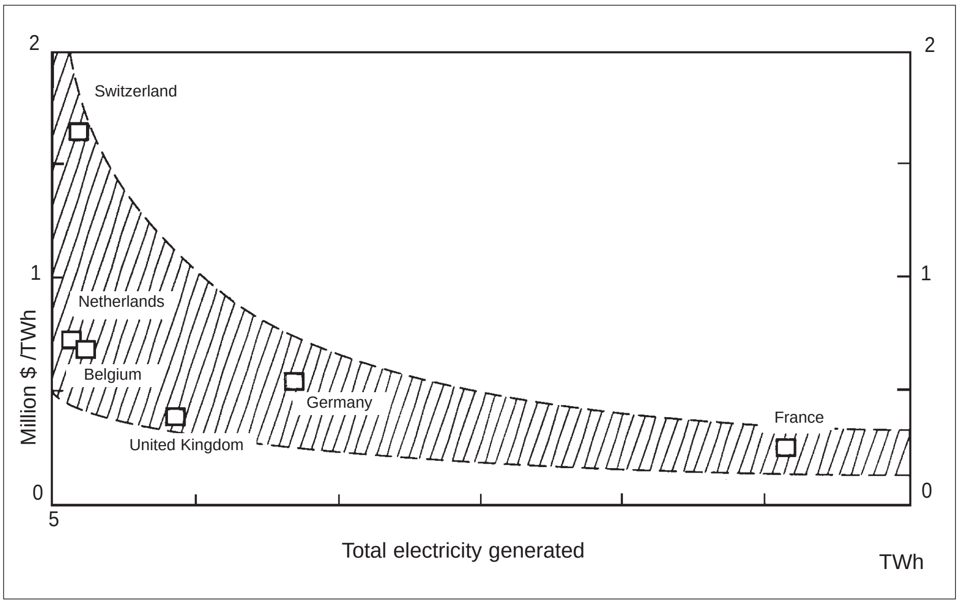
There are, however, a number of factors causing uncertainties in the cost estimates, particularly in those for the disposal of high-level and other long-lived wastes:

- the scale of nuclear programmes in the coming decades will influence the quantities of waste to be disposed of;

Packaging and disposal costs of spent fuel proportioned to total electricity generated from the spent fuel
(in million dollars/TWh)



Packaging and disposal costs of reprocessing waste proportioned to total electricity generated
(in million dollars/TWh)



- radioactive waste management policies and regulations may evolve;
- the scale of the research, development and demonstration work still required depends on the technological progress achieved and may change with evolving policies and regulations;
- repositories may be used in common by several countries on economic grounds, or to reduce the number of sites for safety reasons;
- the costs are sensitive to the discount rates applied and the time-scales involved, for example the duration of pre-disposal storage, the time taken to identify disposal sites and obtain permission for their development, and the time for which institutional control at a disposal site is deemed to be needed.

On the basis of current estimates, the total costs of radioactive waste management are dominated by the cost of encapsulating and disposing of the high-level wastes, whether in the form of vitrified high-level wastes from reprocessing or unreprocessed spent fuel. The corresponding costs for other waste categories are typically a factor of 10 lower. A recent NEA study compared the estimated costs for encapsulation and disposal of high-level wastes, for a number of countries, expressed as the cost per unit of electricity produced. The figures varied by about a factor of four from country to country because of different national nuclear strategies, scale of nuclear programmes, reactor designs and other factors. The costs for reprocessing wastes ranged from 0.4 to 1.65 mills per kWh, and for spent fuel from 0.43 to 1.8 mills per kWh, the differences between the two options being smaller than the uncertainties in these figures. Total nuclear generation costs in the same countries ranged from 28 to 54 mills per kWh, showing that total waste management costs are in all cases a small fraction of total generation costs.

Who pays?

The “polluter pays” principle forms the basis for financing radioactive waste management and disposal in most countries. Application of this principle is intended to ensure that the nuclear operator makes proper provision for dealing safely with the waste and that costs are passed on to those who benefit from the electricity that gives rise to the wastes, through the price they pay for the electricity. Indeed nuclear power is the only major source of energy for which all routine environmental costs are fully recoverable from the consumer; there are no current mechanisms, for example, for covering the cost of atmospheric pollution from fossil-fuelled electricity generation, which falls on the population at large, and frequently on people in other countries who have had no benefit from the electricity produced. A recent study by the NEA of the broad economic impacts of nuclear power concluded that these external costs of emissions from fossil-fired stations, while difficult to quantify accurately, could well be significant in relation to total generating costs.

The application of the "polluter pays" principle is relatively straightforward to apply to some radioactive waste management activities, but not to others. Expenditure on short-term operations, such as effluent clean-up and waste disposal in an existing repository, are covered by the waste producer immediately, either directly out of his investment and operating budget, or by payment to a waste management agency for services rendered. Some stages of longer-term operations, such as the construction and operation of temporary stores, can be covered in the same way. Others, however, such as the deferred disposal of high-level wastes, to allow a period of cooling that may stretch to several decades, involve a comparatively long interval between the time when the waste is generated and the time when the expenditure is incurred. Furthermore, expenditures may continue over a long period, for example for an extended period of monitoring and surveillance of a disposal site after it has been sealed. Such long-term operations require special funding provisions, which will have to take into account uncertainties about the precise nature and timing of activities.

Funding long-term operations

The main reason for developing special solutions to the funding of long-term waste management operations is ultimately a concern for the safety of future generations, providing a reasonable assurance that adequate funds will be available to implement the necessary technical and institutional actions as and when required.

In practice, the funding method adopted will vary from country to country, depending on the waste management strategy selected and on how nuclear programmes develop. Some aspects of the issue, however, are generic. Extended storage of spent fuel or waste, even for a period exceeding 50 years, should not give rise to real financing problems provided it is set up fairly quickly after production. An estimate of the investment required for well-established storage facilities could easily be provided by the nuclear operator, for example under the terms of a contract with a specialised organisation providing such facilities. The costs of maintaining such stores, even over long periods, are too small to create financial difficulties. Nor should disposal in a near-surface or deep underground repository present any serious financing problems provided the repository is in existence or could be established within a relatively short period. The possible costs of surveillance of such a repository, even for periods of a 100 years or more, would again be low enough to cause no financial difficulty.

On the other hand, the disposal of vitrified high-level waste or spent fuel after a long period of storage poses different questions. The time between the generation of the waste and its disposal would be far too long to consider direct participation by the nuclear operators who actually generated the wastes in the costs of moving the wastes, and constructing and operating the disposal sites. Moreover, particularly if nuclear programmes are stopped, there is also the possibility that the nuclear organisations themselves will no longer exist. A number of different methods have been developed to ensure the availability of the necessary funding.

Generally, the costs are covered either by a fee included in the charges for electricity generated by nuclear reactors or by a fee charged on all electricity sold, which would depend on the fraction of total electricity generated by nuclear stations. Control of these funds and the precise uses to which they are put varies from country to country. In a number of countries, for example Spain, Sweden and the U.S.A., money from electricity sales is used to establish an independent fund which is intended to cover the cost of waste disposal. In others, for example Canada, France and Germany, an independent fund has not been established. In most countries, the development costs and the costs of research and development associated with deep geological disposal are paid for by the waste producers.

In general, the overall funding of waste management activities is likely to involve a combination of several financing methods – direct contributions to cover current investment and running costs, payments to specialised waste management bodies, loans and the establishment of funds to cover longer-term commitments.

Chapter 6

SOCIAL ISSUES

Summary

The public is well aware of the danger and longevity of radioactive wastes, and less aware of the corresponding risks from more familar chemical wastes. Detailed descriptions of the methods proposed for radioactive waste disposal tend to emphasise the dangers and time-scales involved. There is little public appreciation of the widespread consensus among the scientific and technical community that these problems are fully soluble by the careful application of currently available techniques.

It is increasingly recognised that fossil-fired generation itself results in undesirable long-term effects. This has enabled the whole nuclear debate to be conducted in a wider context. Recent public opinion polls suggest that the majority of people in OECD countries, while not positively welcoming nuclear power, do now see it as having an essential role in future energy supplies. As a result there should be less opposition to the disposal of the resulting waste, as long as people can be assured that it can be done safely.

Much public concern is focused on the impact of waste management on future generations. In practice, the only way in which obligations to future generations can be addressed is through a framework of laws and regulations applied to current activities. Such laws and regulations need to be formulated on the basis of definitions of long-term radiation protection requirements, and safety assessments have to demonstrate that such requirements can be satisfied. Most countries are now well advanced with this. For high-level and other long-lived wastes, temporary storage (if needed to allow for heat dissipation) followed by disposal deep underground is being confirmed as an effective way of satisfying the requirements both for current and for future generations. Other categories of waste require less extreme management methods to ensure safety and disposals are being implemented in a number of countries.

Some disposal sites may require institutional controls after the end of their operational life in order to confirm their continuing effectiveness and to carry out

any remedial actions that may be needed to maintain safety. In order to minimise the burden on future generations, the period of institutional control should be kept as short as possible. A period of 300 years is recommended as a maximum time beyond which the integrity of a containment system should no longer depend on any human intervention.

The social issues associated with the management of radioactive wastes demand that the public be kept as fully informed as possible, and take the greatest possible part in the decision-making process. In the final analysis, radioactive wastes exist and must be properly disposed of, and an adequate level of political commitment to finding a solution that is acceptable to the public is essential .

Public and media perceptions

Very few people mention radioactive waste when asked general questions about things that concern them. But when people are presented with a list of possible concerns which includes radioactive waste, and are asked to rank them in order of importance, most people put it near the top.

Radioactive waste is commonly perceived as at best an unsolved problem and at worst an insoluble one. It has become, for many people, a symbol of all that they find unacceptable in modern industrialised society. They see it as uniquely dangerous, particularly because of the association with radiation and hence with cancer, one of the most dreaded of diseases. They point to past failures which have resulted in serious pollution, not appreciating that the conditions under which these failures occurred, during early military programmes and mainly in the former U.S.S.R., bear little resemblance to modern conditions and requirements. Many see radioactive waste as an imposed risk with no compensating benefits, being unconvinced by the arguments in favour of nuclear power and generally unaware of the existence of radioactive wastes from medical and other practices. And they see the need for long-term isolation as one that places unacceptable burdens on future generations, and seem less aware of the corresponding risks from more familiar chemical wastes, some of which remain toxic for ever. Descriptions of the techniques proposed for disposal of long-lived wastes in specially engineered repositories deep underground, techniques far more complex and expensive than those applied to other types of toxic waste, tend to confirm the image of a uniquely difficult problem.

Public concern is particularly acute in the immediate vicinity of a proposed disposal site. People living nearby see themselves as being forced to accept other people’s wastes – a prime example of the well known NIMBY syndrome, or “Not

In My Back Yard". Local opposition, sometimes encouraged by non-local members of national pressure groups, has in some cases resulted in postponement or abandonment of disposal projects and even of exploratory research. There is thus a great gulf between public perceptions and the consensus view of the technical and scientific community that the problems are fully soluble by the careful application of currently available techniques.

Media treatment of the issues covers a wide range of viewpoints and opinions. The technical press tends to reflect the technical consensus, highlighting areas of particular scientific and engineering interest. The popular press, not surprisingly, concentrates on more newsworthy topics such as local opposition campaigns, particularly popular demonstrations. Even when media coverage sets out to present a balanced view of the issues, there tends, particularly on television, to be a discrepancy between the scientific weights of the opposing spokesmen, for example with a scientist representing a broad consensus of technical opinion being "balanced", by one representing an extreme minority view. This can result in considerable public confusion, since the result of such a confrontation can be to suggest that there is a high degree of scientific uncertainty when little in fact exists.

An important feature of the public debate on radioactive waste management is that increased technical understanding does not necessarily lead to increased acceptability. Indeed, some studies have shown that public opposition can increase as public understanding rises. This is not, however, an argument against providing the fullest possible information to the public, rather it points to the importance of ensuring that the technicalities of the issue are presented as part of a much wider programme of public information and participation. In spite of these problems, some progress is being made in increasing public acceptance of radioactive waste management activities in some countries. This may be due, in part, to a growing awareness of the part that nuclear power can play in alleviating the problems of greenhouse gas emissions, increasingly being seen as the greatest current threat to the world's environment. Several recent public opinion polls in a number of OECD countries suggest that nuclear power, while not positively welcomed, is now seen by the majority of people as playing an essential role in future energy supplies. As more people come to accept that there is a need for nuclear power, there is likely to be less opposition, at least in principle, to the disposal of the resulting wastes, but only as long as people can be convinced that everything possible is being done to ensure safety.

Responsibility with regard to future generations

Much of the public concern about radioactive waste arises from the perceived long-term nature of the hazard. Many components of the waste do indeed remain radioactive for very long periods, but there is little appreciation of the fact that very long half-life means very low levels of radioactivity, or of the ubiquity of natural radioactive materials with similarly long half-lives in the earth' s crust and in the biosphere. Nevertheless, the problem is a significant one, with some categories of waste remaining potentially dangerous for periods beyond historical human experience, and minimising the burden on future generations has always been a fundamental requirement of radioactive waste management. For this reason, international recommendations are designed to ensure that the level of protection of future generations should be at least equivalent to that of the present generation, and that long-term safety should not depend on the active maintenance of disposal systems beyond a limited period of active surveillance.

In practice, the only way in which obligations to future generations can be addressed is through a framework of laws and regulations applied to current activities. Clearly, no direct legal relationship, for example by way of contract, is possible between those producing the waste and those hypothetical persons who may be affected by it in the distant future. While the precise formulation of the laws and regulations will depend on national conditions and international obligations, the broad approach that is likely to be followed is:

- the political authorities will define an acceptable level of risk for the population for which they are responsible, taking into account the social advantages of the activities giving rise to the wastes and the social costs of waste management;

- they will authorise the use of technologies and management methods that seem to them to be the best available in order to bring the risk to as far below the defined level as reasonably achievable, taking social and economic factors into account (ALARA);

- they will seek the best available guarantees, within the limits of the forecasting methods available, that the solutions chosen are such as to keep the risk below the defined level and ALARA for as long as necessary.

The work that is continuing at national and international level on risk and benefit analysis, safety assessment and the definition of long-term radiation protection requirements is helping to refine these processes, and international agreement on acceptable solutions will provide governments with a more solid basis for decision. At present, the approach currently being pursued by most countries – burial in suitable geological formations at appropriate depths, after any period of storage necessary for heat production to decay – is being confirmed as an effective way of satisfying the requirements for both current and future generations. Current research is concentrating on establishing the safety of specific sites.

An alternative approach to that currently being pursued is being advocated by some pressure groups that are opposed to nuclear energy. They propose that the wastes should be stored indefinitely in surface or near-surface facilities, where they could continue to be supervised and monitored. If such a strategy were adopted, it would enable these pressure groups to keep alive their claim that "no permanent solution to the waste problem exists", and thus strengthen their arguments against nuclear energy. Indefinite storage may appear superficially attractive because of the feeling that any disposal implies loss of control – a concern that "out of sight is out of mind". It is, however, inconsistent with the principle of minimising the burden on future generations. Nevertheless, the concern is a real one. It may be possible to alleviate it by placing more emphasis on long-term monitoring and retrievability of the wastes. Disposal facilities are designed to make monitoring and corrective measures unnecessary but not impossible for future generations.

Institutional controls

The planning, construction and operation of waste storage and disposal facilities are subject to exactly the same type of detailed regulation as any other nuclear installation. Disposal sites, however, may require additional provisions designed to help maintain the effectiveness of the containment system after the end of the operational period, when all the wastes are in place and the facility has been sealed. Particularly important for near-surface disposal facilities, where inadvertent intrusion would be relatively easy, these provisions are generally called institutional controls and have three distinct objectives:

- to prevent any intrusion which might affect the integrity of the containment system;
- to monitor the surrounding environment to confirm that there is no unpredicted release of radioactivity;
- to ensure that any remedial actions that may be necessary to maintain safety are promptly and efficiently carried out and that funds are available for such actions if needed.

The controls can be active or passive. Active controls include environmental monitoring and any necessary maintenance and remedial work. Passive controls include fencing and marking, maintaining records, and administrative restrictions on land use. Even when such controls are not strictly necessary for the purpose of safety, for example for a deep geological repository, they may be set up for the purpose of good administrative practice, maintaining awareness of a disposal site, and providing the public with assurances about continuing safety.

A key issue in considering the effectiveness of institutional controls is the stability of the political and social structures within which they would operate. While some such structures have in the past been fragile, laws, rules and customs designed to protect basic needs such as health and physical safety are generally more durable, not only in normal times but also in periods of major social upheaval. Conditions under which laws designed to ensure physical security are likely to fail totally, such as all-out warfare, would pose risks far in excess of any associated with the possible failure of containment of a near-surface waste disposal facility, and even such extreme events as a full-scale nuclear war would not affect the integrity of a deep repository.

Perhaps a more likely scenario than total social collapse is a gradual forgetting of the existence of a disposal facility, as a result of many years of monitoring showing no failure of containment or a gradual loss of interest by society at large. In such a case, inadvertent intrusion, for example when digging foundations for a building on the site of a near-surface disposal, could still in principle result in unacceptable levels of radiation exposure, and this is one of the factors that sets an upper limit to the concentration of long-lived radionuclides in wastes suitable for near-surface disposal.

It is generally assumed that institutional control measures can contribute to the safety of a containment system for a period of some hundreds of years, and a cautious approach would be to set a period of around 300 years as a maximum time beyond which the integrity of a containment system should no longer depend on any human action.

Public information and participation in decision-making

The social issues raised when considering the management of radioactive wastes demand that the public be as fully informed as possible about the issues at stake and take the greatest possible part in the decision-making process. The provision of information to the public about all stages of radioactive waste management is now common in all countries, usually by government information agencies, by waste producers and by waste management agencies. Procedures for public participation vary considerably from country to country, ranging from the use of national and local referenda to less formal public consultation exercises. The public can be involved at various or all stages, from the development of an overall national strategy to the implementation of a particular activity at a specific site.

In several countries, strategic decisions based on advice from regulatory agencies and technical experts have in the past been made by government, with little public consultation. The public was only involved when a particular technical approach, or occasionally a potential site, had already been selected, and attempts were then made to communicate these decisions with supporting arguments, in the hoped achieving public understanding and acceptance. This approach often resulted in considerable public opposition, nationally and, in particular, at the selected site or sites, and proposals often had to be significantly modified or even withdrawn as a result of the strength of the opposition. In some countries the failure of such approaches has led to the introduction of procedural innovations or to broader institutional changes.

In other countries, the public was kept more fully informed and was given opportunities to participate in the discussions and decisions from an early stage. Even these countries, however, have experienced difficulties in agreeing disposal sites, particularly for long-lived wastes. There is thus no single method of communicating with and involving the public that will ensure smooth progress in the implementation of waste management plans. The key to achieving public acceptability appears, on the basis of experience in OECD countries to date, to be to invite public participation in the maximum number of stages of the decision-making process, both at national and at local level, together with a policy of maximum openness on the part of the government, the regulatory authorities, the nuclear industry and the waste management agencies. Some element of public consultation is now part of the approval and licensing processes in most countries. In the final analysis, however, radioactive wastes exist and must be properly disposed of, and an adequate level of political commitment to finding a solution that can be accepted by the public is essential.

Chapter 7

THE INTERNATIONAL DIMENSION

Summary

The risk of transboundary pollution by radioactive materials, the transport of spent fuel between countries, and the risk of nuclear weapons proliferation, all provide an international dimension to the management of radioactive waste. At the same time, the problems associated with radioactive waste management are common to most countries, including those without a nuclear power programme. The international bodies provide a forum within which common standards can be established, and through which the benefits of national programmes can be shared within the wider community.

There are a number of collaborative research projects that are managed by International bodies. The most significant areas of international co-operation in the field of radioactive waste management are concerned with repository safety assessment, particularly with providing assessment methods that are technically reliable and widely accepted. An important requirement for the future is to help to ameliorate problems resulting from inadequate past practices in the former U.S.S.R.

None of the international bodies play a direct role in the management of radioactive waste itself, although the IAEA does play an important monitoring role as part of its obligations under the Nuclear Non-proliferation Treaty. *Consideration has been given to the provision of an international disposal facility, but agreement on the siting of such a facility seems unlikely in the near future.*

The globalisation of waste issues

The safe management of wastes that could pose a threat to the environment or to human health is not purely a national problem, and there has been a growing realisation over the past few decades that pollution is no respecter of frontiers. The problem first emerged in the context of acid rain caused by the atmospheric transport over long distances of the gaseous by-products of fossil fuel combustion. Some countries were clearly experiencing environmental damage, to forests, rivers, lakes and buildings, as a result of activities far beyond their national boundaries, from which they were receiving no benefit. More recently, Chernobyl, and increasing concerns about global warming and the partial destruction of the earth's protective ozone layer, have led to a wide international debate on transboundary and global pollution problems, and in some cases to progress in the form of international treaties and agreements to limit emissions.

The problem of transboundary pollution by radioactive materials arises mainly in the context of some gaseous and liquid effluents, which have resulted in negligibly small additions to natural background radiation; it has also arisen in the context of atmospheric nuclear weapons testing and the Chernobyl accident. There is no possibility of radioactive material from a near-surface or deep underground waste disposal facility reaching the surface more than a few tens of kilometres from the repository, even after very long periods, and so no transboundary problems are likely to occur unless the facility is sited very close to a national frontier. However, the times for which radioactive wastes must be isolated are long compared with the periods for which the frontiers themselves are likely, on the basis of past experience, to remain stable.

An additional issue sometimes resulting in public concern is the transport of used nuclear fuel from the country of origin to one that offers a commercial reprocessing service, together with the return of the reusable fuel and the resulting wastes. The transport of plutonium, in particular, has recently been highlighted by some pressure groups as a particularly contentious issue, both because of its toxicity and because of the fear of diversion and nuclear weapons proliferation. However, the strict application of national and international transport regulations and physical security measures should be sufficient to keep these hazards within manageable limits.

Nevertheless, radioactive waste, in common with some other types of waste, has become a global issue which can seldom be dealt with entirely by one country in isolation, and there are a number of international treaties and agreements designed to minimise the possibility of conflicts and disputes and to resolve any problems that might arise.

International organisations and their role

International bodies play an important role in developing recommendations on which national criteria, regulations and standards for the management of radioactive wastes are based, encouraging and facilitating collaboration between national programmes, reviewing progress and achieving technical and regulatory consensus, and disseminating information to governments and to the wider public. The activities of the main international bodies are given below.

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) reports regularly to the General Assembly of the United Nations and publishes comprehensive reviews of the scientific and medical evidence on sources, effects and risks of radiation, which are widely accepted as the most complete and authoritative source of information on these subjects. The reviews include assessments of the possible consequences of waste disposal activities.

The International Commission on Radiological Protection (ICRP) is an independent body of scientific and medical experts which issues general recommendations for the radiation protection of workers and the public, and specific recommendations relating to radioactive waste disposal. ICRP recommendations form the basis for national and international regulations, criteria and standards.

The International Atomic Energy Agency (IAEA) is an international agency of the United Nations family which has as its principal objective "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world". Its integrated waste management programme exists to assist Member States in the safe and effective management of radioactive wastes by organising the exchange and dissemination of technical, safety and regulatory information on the subject, providing guidance, technical assistance and training, and supporting research and development in the field.

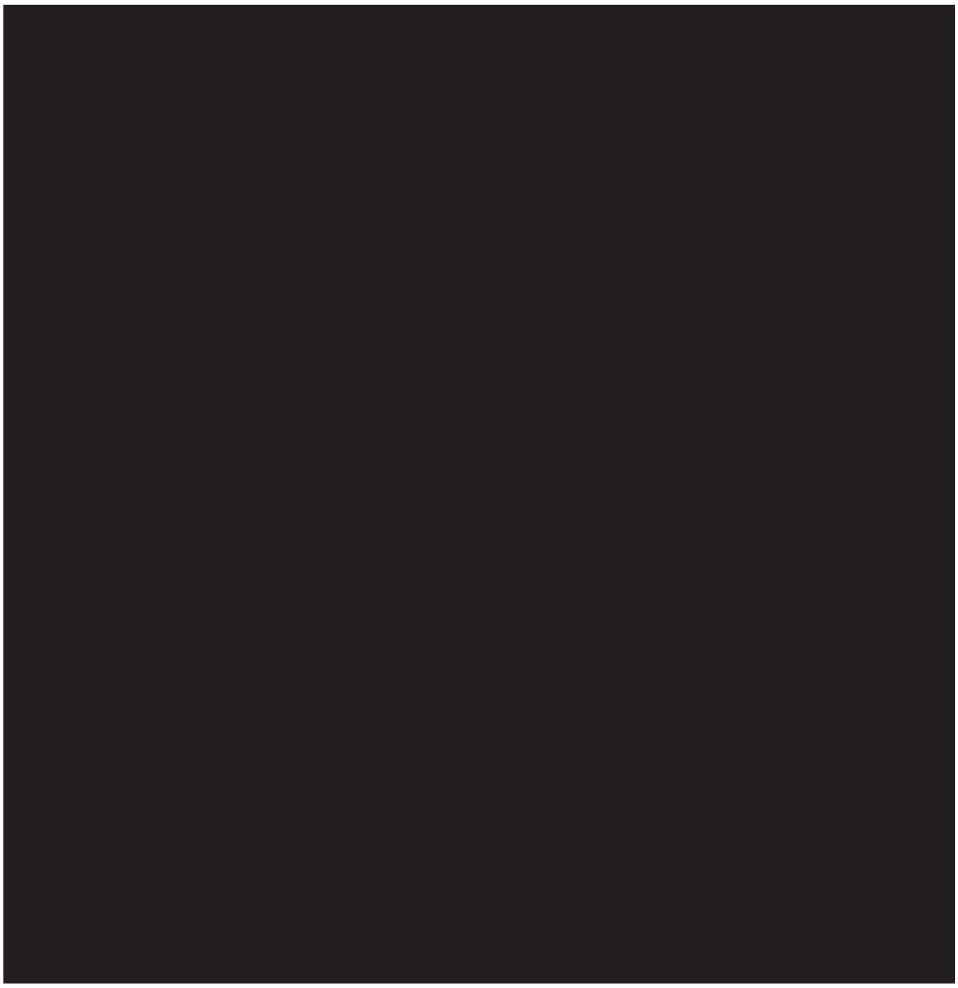
The World Health Organisation (WHO) is an agency of the United Nations with primary responsibility for international public health matters. It has published or collaborated in a number of studies relating to the health aspects of nuclear power production, including those of radioactive waste disposal.

The OECD Nuclear Energy Agency (NEA) has as its primary objective the promotion of the development of nuclear power as a safe, environmentally acceptable and economic energy source. It seeks to achieve this objective by serving as a forum for the exchange of information among specialists, helping to harmonise national legislation, developing collective opinions on key technical policy issues, and encouraging consultations on the nuclear programmes of its member countries. A unique role of the NEA is to create international undertakings and projects in which Member countries jointly finance and operate research and development programmes, or set up information exchange programmes, as a stepping stone to the development of nuclear power. In the field of radioactive waste management, the main such projects have been:

- the International STRIPA Project, an underground laboratory to investigate the suitability of granite as a medium for isolating radioactive wastes;
- the Geochemical Data Bases Project, to provide the primary geochemical modelling data needed to assess the performance of radioactive waste disposal systems;
- the Alligator Rivers Analogue Project, to determine the long-term physical and chemical processes likely to influence the movement of radionuclides through rock masses;
- the Co-operative Programme on Seabed Disposal of High Level Radioactive Waste, to study the technical feasibility and safety of this disposal concept;
- the Co-operative Program on the Exchange of Scientific and Technical Information Concerning Decommissioning of Nuclear Installations, to provide a forum for the exchange of experience and to develop the database needed for decommissioning large nuclear power plants.

Credit: OECD/NEA.

Research into the suitability of granite for isolating radioactive waste was carried out at the STRIPA International Project under the auspices of the OECD Nuclear Energy Agency.



Credit: NEA Co-operative Programme.

The remote manipulator for dismantling the Niederaichbach reactor in Germany.

The Commission of the European Communities (CEC) bases most of its activities in the field of radioactive waste management on the *Euratom Treaty*. The provisions of this treaty which govern radioactive waste management activities are the promotion of research and the dissemination of technical information, the establishment of uniform safety standards to protect the health of workers and the general public and ensure that they are applied, and the establishment with other countries and international organisations of relationships to foster progress in the peaceful uses of nuclear energy. The CEC programmes are coordinated through a Community Plan of Action, which provides for:

- continuous analysis of the technical situation, designed to keep the Community and its Member States up to date on work and achievements in all areas of radioactive waste management;
- examination of measures which could ensure the long-term or permanent storage of radioactive wastes under optimum conditions;
- consultation to ensure that the maximum benefit is obtained from the work of national, Community and international programmes;
- continuity of Community research and development programmes during the plan;
- provision of information to the public.

The *Euratom Treaty* and provisions that are adopted by the Council and by the Commission are legally binding throughout the Community. Relevant requirements include the provision of general data relating to any plan for the disposal of radioactive waste in any form that is likely to contaminate the water, soil or airspace of another member state, and detailed environmental impact assessments in conformity with a detailed procedure for important projects, including installations for the management of radioactive waste

The pooling of experience, information and resources

International collaboration to ensure the maximum benefit of national research and development programmes has long been a feature of the nuclear industry and this is particularly marked in the field of radioactive waste management, where there are few commercial requirements to constrain such collaboration. The field is clearly one where many countries can benefit from individual technical advances and innovations, including countries which have no nuclear power programme but still have to deal with radioactive wastes from medical, industrial and research sources.

There are many examples of the benefits of collaborative programmes, such as the joint NEA programmes listed above and those of the CEC and the IAEA. The most significant area of international co-operation is concerned with repository safety assessment, particularly with providing assessment methods that are technically reliable and widely accepted. Some of the NEA’s projects in this area are:

- the setting up of international databases, for example on the interactions of various radionuclides with repository construction materials and various types of geological formations, and on relevant thermodynamic processes;

- the development of calculation codes and probabilistic assessment models for repository safety;
- international validation of these codes and models by comparison with experimental observations, including those from natural analogues.

The objective of all these projects is to reach a higher level of confidence in all the techniques that seek to predict the long-term behaviour of repositories, as well as their safety. The results so far have been highly encouraging, and played an important part in enabling the NEA to issue Collective Opinions, as described in Chapter 4.

There is widespread interchange of information on all these collaborative programmes through publications, conferences and seminars, and exchanges and attachment of staff. For example, the results of the work at STRIPA, together with results from other underground laboratories in Belgium, Canada, Germany, Switzerland and the United States have been presented in a series of international meetings and have been widely published, enabling them to contribute to radioactive waste disposal projects in the collaborating countries and elsewhere. The pooling of resources in this and other areas has thus clearly helped to maximise the cost-effectiveness of radioactive waste management research and assessment activities worldwide.

An important requirement for the future will be to help to ameliorate the consequences of inadequate past practices and specific accidents in the former U.S.S.R., particularly in the military field, applying well established national expertise and resources, as well as financial resources, through international collaborative programmes. In this context, the NEA is participating in the international Arctic Monitoring and Assessment Programme, which is studying pollution in the Arctic, including the consequences of radioactive waste disposals in the Arctic Seas.

Creation of an international repository

The quantities of radioactive waste that result from nuclear electricity generation are such that it would be possible for a single repository to meet the needs of several countries.

The studies that have been carried out on the feasibility of international repositories suggest that there are not likely to be significant technical, economic or legal obstacles. However, the political problems associated with siting make such repositories unlikely in the near future.

Chapter 8

CONCLUSIONS

The primary objective in the management of radioactive waste is to protect current and future generations from unacceptable exposures to radiation from the wastes.

Radioactive wastes derive from medical, industrial, research and military sources as well as from nuclear power. Wastes from all these sources exist now and must be dealt with safely, Irrespective of the future of nuclear power programmes. The greatest public concern is directed towards nuclear wastes, particularly those with the longest life.

The level at which exposure to radiation can be considered to be acceptable is defined within national regulations based on international recommendations developed by the ICRP. These regulations are applied to all activities that could potentially give rise to radiation exposure. Additional regulations apply specifically to radioactive wastes.

Management processes have been developed for all categories of radioactive waste. Processes have been implemented in many countries for the disposal of low and some short-lived medium-level wastes. No process has yet been implemented for the disposal of long-lived wastes, although there is widespread consensus within the technical community that this can be achieved using currently available techniques. All wastes for which disposal has not yet been implemented are currently held in stores with appropriate safety and security measures.

Before any management process can be established, the particular implementation needs to be assessed in order to ensure that regulations will be satisfied under all conceivable circumstances. It is generally agreed within international bodies concerned with radioactive wastes that the methodology and the technical tools now exist for carrying out thorough long-term radiological assessments of disposals at chosen sites. Assessments at a number of specific sites suggest that all the safety requirements can be met.

Disposal of radioactive waste is expensive in absolute terms, although costs are small compared with the benefits in terms of the value of the electricity generation that has given rise to that waste. Funding mechanisms have been established in most OECD countries that enable costs to be met decades in the future while satisfying the principle of "the polluter pays." Before any management process can be implemented, public acceptance of the basic principles and the specific proposal must be obtained. Public debate needs to be conducted within a sufficiently broad context, addressing energy requirements as well as environmental impacts, and recognising that few solutions to the energy supply problem are without future impact.

The international bodies, including the Nuclear Energy Agency, have an important role to play. Few national activities are entirely without transnational implications, and as a result international regulation needs to be established. In addition, international collaboration on research into disposal and assessment techniques can encourage best practice throughout the international community, and can give the public greater assurance that their safety requirements are being met.

ANNEX

National Radioactive Waste Management Programmes in NEA Countries

BELGIUM

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

Nuclear energy provides 55.8% of Belgium's electricity, from seven reactors with an installed capacity of 5.5 GW (1994).

Until 1974 spent fuel was reprocessed at the EUROCHEMIC plant. It is now reprocessed at La Hague, France, and the resulting wastes will be returned to Belgium for temporary storage and final disposal.

NATIONAL WASTE MANAGEMENT STRATEGY

Wastes other than reprocessing wastes are conditioned, either on the site where they arise or in a central processing facility at the Mol-Dessel site managed and operated by Belgoprocess, the subsidiary company of ONDRAF. All wastes will be stored at Mol-Dessel until appropriate disposal facilities are developed.

Wastes containing short-lived low-level radionuclides will be disposed of above ground level or deep underground, depending on the outcome of current evaluations. Wastes containing long-lived medium-level radionuclides, and high-level and heat-generating wastes arising from reprocessing, will be disposed of deep underground.

RESPONSIBILITIES

The National Agency for Radioactive Waste and Enriched Fissile Materials (ONDRAF) is an autonomous public agency operating under the guardianship of the Minister having energy among his responsibilities. It is responsible for the management of all radioactive wastes produced in Belgium. It is financed by the waste producers.

ONDRAF also manages a special fund for the financing of long-term operations, sponsored by the waste producers.

STORAGE

Spent fuel is stored at the power stations until it is sent for reprocessing. No central spent fuel storage facility is therefore needed.

All conditioned wastes awaiting disposal, including returned reprocessing wastes, are or will be held at Mol-Dessel on the Belgoprocess site:

- Conditioned low-level wastes are stored in prefabricated concrete buildings. Those being returned from La Hague are stored in a new facility.
- Conditioned medium-level wastes resulting from reprocessing at the EUROCHEMIC plant and from nuclear power plants are held in shielded storage bunkers. Those being returned from La Hague are stored in a new facility.
- High-level wastes from EUROCHEMIC, vitrified in the PAMELA plant, are stored in air-cooled storage pits in a bunker building. Those being returned from La Hague are stored in a new facility.

DISPOSAL

ONDRAF is co-ordinating research and development of final disposal for conditioned low-level and short-lived wastes in continental formations, and in deep clay layers for long-lived high-level wastes. The work is carried out in co-operation with various national and international organisations, as well as with the waste producers, who finance the programmes.

No decision has yet been taken on the disposal system to be used for short-lived low-level wastes. Several zones which might be acceptable for surface or near-surface repositories have been identified. In addition to surface or near-surface disposal, ONDRAF is also evaluating disposal in deep formations on the same site considered for high-level and other long-lived wastes.

A study of potential deep geological formations, performed by the National Nuclear Research Centre (CEN), resulted in the decision to investigate the Boom clay formation in the Mol-Dessel area. An underground laboratory has been constructed in this formation at a depth of 230 m, and an extensive research programme will continue for several years.

While no final repository design has yet been agreed, the underground facilities will probably consist of a network of interconnected circular tunnels, 3 to 4 m in diameter. The high-level waste canisters (vitrified waste) could be placed directly in the central axes of the galleries. Other waste packages could be placed in separate galleries. The galleries would be backfilled to provide a good support structure, possibly using the excavated clay, which might be mixed with other natural or synthetic material. Site confirmation studies and demonstration operations will probably continue until around 2015, and would be followed by final conceptual design, licensing and construction, with waste emplacement due to start around 2035.

CANADA

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

Nuclear energy provides 18.8% of Canada's electricity, from 22 reactors with an installed capacity of 15.4 GW (1994).

Spent fuel is currently stored at the power stations pending the development of disposal facilities. Research has been carried out on reprocessing but there are currently no plans to use the technology.

NATIONAL WASTE MANAGEMENT STRATEGY

Uranium has been mined since the early 1930s and over 200 million tonnes of tailings have been generated. Uranium tailings are decommissioned on site. Successful decommissioning has been achieved at a few sites in Saskatchewan and Ontario. Other sites are either being decommissioned or are still in operation.

All wastes from nuclear power generation are stored pending the development of permanent disposal facilities.

Wastes produced by AECL from isotope production and from R&D activities are currently stored at the Chalk River and Whiteshell Laboratories. Waste produced by universities, hospitals and a number of other producers are also stored at the Chalk River Laboratories. AECL is currently seeking a construction license for a prototype Intrusion Resistant Underground Structure (IRUS) for disposal of short-lived wastes.

Spent fuel will be disposed of 500 to 1000 m underground in the rock of the Canadian Shield. Ontario Hydro and AECL are examining options for the disposal of other long-lived wastes.

RESPONSIBILITIES

The primary responsibility for the management of radioactive wastes in accordance with regulatory criteria established by the Atomic Energy Control Board (AECB) rests with the producers/owners of the wastes.

There are two federal government agencies with responsibilities in radioactive waste management: the AECB, the Canadian nuclear regulatory agency that was established in 1946 by the *Atomic Energy Control Act*, and AECL, which is responsible for research in radioactive waste management. The Low-level Radioactive Waste Management Office (LLRWMO), the federal agency responsible for the clean-up of historic low-level radioactive wastes that are the responsibility of the federal government, is operated out of AECL.

Funding for storage and disposal of low- and medium-level waste is the responsibility of the producers of the wastes. Research and development for new and improved management technologies is funded by AECL and Ontario Hydro.

Funding for the nuclear fuel waste management programme was principally provided by the Government of Canada until 1987. Ontario Hydro is currently providing substantial funding and is collecting funds from its customers which will be applied towards the cost of disposing of Ontario's spent fuel. Utilities in New Brunswick and Quebec have similar arrangements.

STORAGE

Spent fuel is stored at the power stations and will remain there until a disposal facility is in operation. The fuel is initially discharged to primary bays and, after a cooling period, transferred to auxiliary bays. Spent fuel is in dry storage at a number of sites. The systems allow for storage for up to 50 years, and this could be extended if necessary.

Low- and medium-level wastes are mostly stored at the Ontario Hydro Bruce Nuclear Power Development site and at AECL's Chalk River Laboratories and Whiteshell Laboratories. The facilities consist of concrete-lined trenches, tile holes, above-ground storage buildings, above-ground reinforced concrete structures, and in-ground steel containers in concrete-lined boreholes.

DISPOSAL

National policy encourages waste producers to establish disposal facilities for low- and medium-level wastes for their own needs.

AECL is in the process of obtaining regulatory approval to construct an Intrusion Resistant Underground Structure (IRUS) at the Chalk River Laboratories, consisting of reinforced concrete in-ground modules, each 30 m long, 20 m wide and 9 m deep. The packaged waste, in the form of steel drums, bales and standardised boxes, will be stacked in the modules, on a base of compacted buffer material, and the spaces between filled with sand. After the modules are filled, they will be covered with a concrete cap overlaid by an engineered cover containing barrier and drainage features.

Ontario Hydro, the largest producer of low-level wastes, is planning to have a disposal facility in operation by 2015. Three options are being considered:

- an independent facility;
- a facility to be co-located with a spent fuel disposal facility yet to be developed;
- collaboration with other producers and the federal government to develop a joint multi-user Canadian disposal facility.

The LLRWMO will develop, as required, a user-pay service for the disposal of low-level waste produced on an ongoing basis.

AECL has conducted a 16-year research programme to develop a disposal concept for spent nuclear fuel based on a geological repository in crystalline igneous rock of the Canadian Shield. The concept is based on burial, at depths of 500 to 1000 m, using a series of engineered and natural barriers. The major research facility is the Underground Research Laboratory, in Whiteshell, Manitoba.

The concept is currently undergoing a federal Environmental Assessment and Review Process. The issue of siting will not be addressed until the concept itself has been found to be technically feasible, safe and publicly acceptable. A decision is not expected before 1997. Ontario Hydro has approved a waste management strategy that has as an objective first disposal of nuclear fuel waste in 2025.

A Siting Task Force has been active for several years seeking to acquire a site for the long-term management of contaminated soils and wastes, mainly from the processing of radium and uranium ores, for which the federal government has assumed responsibility. The town of Deep River, Ontario, has volunteered to host a rock cavern disposal facility for these wastes, and an agreement in principle has been approved by the town in a referendum. If the government agrees to proceed, the facility is to be located on AECL's Chalk River Laboratories' property.

FINLAND

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

Nuclear energy provides 29.5% of Finland's electricity production, from four reactors with an installed total net capacity of 4 GW (1994).

In the past spent fuel from the two VVER reactors at Loviisa has been transported back to Russia after five years' storage at Loviisa. No reprocessing wastes have been returned back from Russia to Finland. This arrangement has been in accordance with the objectives of the Finnish nuclear waste management policy of November 1983. At the end of 1994 the Parliament approved an amendment to the *Nuclear Energy Act* stating that in the future Finland shall itself take care of all the nuclear wastes generated in the country. Consequently, the return of spent fuel back to Russia is not allowed after 1996.

To implement in practice the renewed policy of spent fuel management, the two Finnish power companies (Teollisuuden Voima Oy [TVO] and Imatran Voima Oy [IVO]) have agreed to co-operate for the final disposal of spent nuclear fuel. For this aim it was decided to establish a joint company which will start operating early in 1996.

NATIONAL WASTE MANAGEMENT STRATEGY

Operating wastes (low- and medium-level) are conditioned and stored on site at the power stations. Repositories for these wastes are either in operation (at the Olkiluoto power station site) or under construction (at the Loviisa power station site).

Spent fuel will be disposed of in a deep underground repository from 2020 on.

RESPONSIBILITIES

Each producer of nuclear waste is responsible for its safe management and disposal, and for the financing of these operations. The utilities levy funds for waste management during the operation of the nuclear power plants.

The main authority is the Ministry of Trade and Industry, supported by the Advisory Committee on Nuclear Energy. The State Nuclear Waste Management Fund supervises and handles financial liability issues.

Responsibility for the control of nuclear safety, including waste management, belongs to the Finnish Centre for Radiation and Nuclear Safety, supported by the Advisory Committee on Nuclear Safety.

STORAGE

Spent fuel and other wastes are stored at the power plants until they are disposed of in Finland.

As a result of the policy change of spent fuel management, the alternatives for increasing the interim storage capacity for spent fuel at the Loviisa power plant are being studied during 1995. The present capacity is for about 10 years of spent fuel of which less than half has been used in the previous practice of transporting it back to Russia.

At Olkiluoto, the spent fuel is cooled for a few years in water pools in the reactor building, then transferred to a separate waterpool-type facility on the site for long-term storage. The design of this facility allows for a gradual expansion of capacity to meet the requirements for storage space for the entire lifetime of the current reactors.

Before transfer to the final repository the reactor wastes are temporarily stored and conditioned at the power plants.

DISPOSAL

The nuclear power plant sites at Olkiluoto and Loviisa were chosen at the end of the 1970s as candidate locations for repositories for low- and medium-level wastes. Comprehensive investigation programmes have confirmed the suitability of both sites. A repository constructed at Olkiluoto has been in operation since May 1992 and another repository is under construction at Loviisa.

The Olkiluoto repository consists of two separate vertical silos excavated in crystalline rock under the Olkiluoto island between 60 and 100 m below sea level. The silo for bituminised medium-level wastes consists of a thick-walled concrete silo inside the rock silo. No backfilling will be used inside the concrete silo. The empty space between the concrete silo and the rock will be filled with crushed rock. The silo for dry operating wastes is of shotcreted rock. In both silos the waste drums are emplaced within concrete boxes each containing 16 drums.

The Loviisa repository is planned to consist of a cavern for immobilised wet wastes and tunnels for dry operating wastes, at depths of 110 m. The immobilised wet wastes will be placed in concrete containers surrounded by concrete walls and a backfilling of crushed rock around the concrete walls. The repository is planned to be commissioned in 1997.

The repository concept being developed for spent fuel is emplacement in boreholes drilled in the floor of tunnels to be excavated at a depth of about 500 m in good-quality crystalline rock. The spent fuel will be encapsulated in double-layered copper-steel canisters, the spaces between the fuel elements being filled with suitable granular material. A new design concept is being studied for the inner layer based on a nodular cast iron insert eliminating the need of stabilising filler inside the canister. The gaps between the canisters and the rock walls of the boreholes will be filled with compacted bentonite and the tunnels backfilled with a mixture of sand and bentonite.

Preliminary site investigations have been completed at five candidate sites. A safety analysis, based on the repository design described above, concluded that the planned disposal system fulfils the safety requirements and that suitable places for the repository could be found at each of the five investigation sites. Three sites have been selected for further detailed characterisation and a final choice should be made in the year 2000. Supplementary investigations will then be carried out at the chosen site until 2010, and, subject to licensing procedures, commissioning is planned to take place in 2020.

FRANCE

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

Nuclear energy provides approximately 75% of France's electricity, from 56 reactors with an installed capacity of about 58 GW (1995). Four reactors with a capacity of 5.6 GW are under construction.

Spent fuel is reprocessed at La Hague (enriched uranium) and Marcoule (natural uranium). Long-lived high-level waste resulting from reprocessing are stored on site where they are produced, pending a definite solution.

NATIONAL WASTE MANAGEMENT STRATEGY

Short-lived wastes are disposed of in surface repositories. The Centre de la Manche has entered in its closing phase after receiving waste from 1969 to 1994. The Centre de l'Aube was commissioned in 1992 and should satisfy the country's needs for several decades.

With regard to long-lived high-level wastes, Parliament voted a law in 1991 prescribing that research options be pursued. The government and Parliament have agreed to meet again in 2006 in order to resolve the issue in light of the results obtained. If deep geological disposal is chosen, the plan would be for a deposit to be commissioned before 2020.

RESPONSIBILITIES

The National Agency for Radioactive Waste Management (ANDRA) is responsible for all long-term operations associated with radioactive waste management, namely:

- to participate, in co-operation notabily with the Commissariat à l'énergie atomique (CEA), in the definition and activities of R&D programmes relating to radioactive waste management;

- to ensure the management of long-term storage facilities either directly or through an agent acting on its behalf;

- to design, site and build new storage facilities in light of long-term prospects for the production and management of waste, and to undertake any necessary study to this end, namely the implementation and operation of underground laboratories to study deep geological formations;

- to define, in accordance with safety rules, specifications for processing and storing radioactive waste;

- to list the state and location of all radioactive waste in the country.

ANDRA is funded by the waste producers. It also receives a small governmental grant covering the costs of establishing the national inventory.

The waste producers are responsible for all the operations needed to put the wastes into a form suitable for disposal, and consistent with the ANDRA specifications. ANDRA controls the application of these specifications by the waste producers.

Public authorities are responsible for the broad outline of waste management policy, legislation and technical regulations. Safety authorities control ANDRA's operations; radioactive waste management facilities are basic nuclear facilities and are consequently subject to the regulations in force.

ANDRA reports to the Ministers responsible for the Industry, Research and the Environment.

STORAGE

After conditioning short-lived low-level wastes are stored in ANDRA's storage facilities (currently the Centre de l' Aube).

Spent fuel is stored in pools at the reactor site as soon as it is removed from the reactor. After being transferred to the reprocessing plant, it is stored in pools at the front end of the process line.

After reprocessing, high-level waste are stored, first in liquid form in high-integrity ponds, then after vitrification, in air-cooled structures. Long-lived waste are also stored in structures on the site under the responsibility of the producers, until the government and the Parliament decide upon a final solution.

DISPOSAL

Since 1969 short-lived waste are disposed of in surface facilities at Centre de la Manche. Concrete “monoliths” and “tumuli” containing waste are capped with a leak-proof cover to protect the waste from rainfall and a layer of seeded topsoil. The Centre contains a little over 500 000 m^3 of waste and does not receive any waste any more.

A new facility, the Centre de l’Aube, started operations in 1992. Packages are placed in engineered structures made of concrete. Once filled, each structure will be capped by a concrete slab. A leak-proof cover will then cover all workings. The Centre can accommodate 1 million cubic metres of waste and will remain in operation for several decades.

Long-lived high-level radioactive waste are undergoing extensive research today. One option deals with reversible and non-reversible disposal in deep geological formations, notably through the creation of underground laboratories.

Following a consultation period with the public, the government, on the recommendation of a “negotiator”, has authorised ANDRA to undertake field studies in four departments: Meuse, Haute-Marne and Gard for deep clay formations, and Vienne for granite. In order to specify the siting conditions for ground characterisation laboratories, ANDRA must propose to public authorities a location for two of such laboratories to be constructed somewhere in those four departments.

GERMANY

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

Nuclear energy provides 29.3% of Germany's electricity, from 21 reactors with an installed capacity of 22.6 GW (1994).

Spent fuel is stored at the reactor sites for up to 10 years. Some is sent abroad for reprocessing or to central interim storage facilities. Spent fuel stored in central interim storage facilities will be reprocessed or conditioned for emplacement in a repository, when the appropriate facilities are available.

NATIONAL WASTE MANAGEMENT STRATEGY

All categories of waste will be disposed of deep underground, after an appropriate period of storage. More particularly, the steps are as follows: (1) interim storage; (2) reprocessing or conditioning; and (3) disposal.

RESPONSIBILITIES

The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) is the competent authority for radioactive waste management, and supervises the licensing authorities in the Federal States and the Federal Office for Radiation Protection (BfS). It is advised by the Reactor Safety Commission and the Radiation Protection Commission.

The Federal Minister for Research and Technology is responsible for basic research and development work on radioactive waste and disposal.

The Federal States are the licensing and supervising authorities for most of the nuclear installations. Repositories are licensed by the Federal State concerned, and supervised by BfS. Spent fuel and conditioned high-level waste interim storage facilities are licensed by BfS, and supervised by the Federal State concerned.

The Federal Government is responsible for the planning, construction and operation of repositories for radioactive waste, with the BfS as the responsible authority. The Federal States are obliged to build collection points for the interim storage of the radioactive wastes arising in their area from the application of radioisotopes in industry, research and medicine. All other waste management procedures (*i.e.*, storage, reprocessing, waste conditioning, transport and interim storage) are the responsibility of the waste producers (*e.g.*, the operators of nuclear power plants). The German Company for Construction and Operation of Repositories (DBE) is involved in the construction of repositories and will operate them on behalf of BfS.

All costs associated with radioactive waste and spent fuel management are borne by the waste producers. The site-specific costs for research and development, as well as investigation and construction of repositories are financed by the BMU but reimbursed by the waste producers on an annual basis. Basic research and development work is financed by the Federal Minister for Research and Technology.

STORAGE

Some wastes with negligible heat generation are stored for an interim period on the sites where they are produced, others in interim storage facilities and collection points of the Federal States.

Spent fuel is stored in ponds at the power stations and central interim stores exist at Gorleben, Ahaus and Greifswald. The first two of the central facilities are for the dry storage of spent fuel elements in storage flasks. Greifswald is a pool-type facility. This will be replaced by a dry-storage facility in 1996 at the same site.

DISPOSAL

Since the early 1960s the policy has been to dispose of all radioactive wastes deep underground, concentrating initially on salt domes.

Research and development into deep disposal has been executed since 1965, mainly using the former salt mine at Asse. Demonstrations of low- and medium-level waste disposal were carried out until 1978. R&D work now focusses on long-term safety of high-level waste.

A site at Gorleben has been studied since it was nominated by the State of Lower Saxony and the Federal Government in 1977. The repository would be built at a depth of about 900 m in a salt dome below a gypsum top cap. Wastes with negligible heat generation would be stacked in disposal rooms. Heat generating wastes would be placed in galleries or in vertical boreholes. Underground tests and detailed repository designs should be completed by the late 1990s and, if approved, the repository is scheduled to become operational in 2010 at the earliest.

A former iron ore mine at Konrad, at depths between 800 and 1300 m, was identified as a possible repository site for low- and medium-level wastes with negligible heat production within the framework of a research and development programme between 1975 and 1982. The packaged wastes would be emplaced in chambers with an average diameter of 7 m and up to 1000 m long. The licensing procedure with an additional programme of underground exploration and safety assessment began in 1982 and a decision on the licence application is expected soon.

The former salt mine at Morsleben in the former German Democratic Republic has been used since 1981 for the disposal of low- and medium-level wastes, following several years of investigation and test operations. The total volume of underground openings is about 5 million cubic metres. On reunification, BfS became responsible for the repository. Approval for continuing operation has been granted, and a new licence will have to be sought in the year 2000 for use of the site to continue.

ITALY

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

There are currently no operating nuclear power stations in Italy. The three existing power stations have been shut down, and construction of a further station has been halted.

Some of the spent fuel from past power station operations is being reprocessed at Sellafield, U.K., with the resulting wastes being returned to Italy. The remaining spent fuel is stored at the power stations.

NATIONAL WASTE MANAGEMENT STRATEGY

Wastes from power plants and experimental fuel cycle facilities are stored at their point of origin. Wastes from medicine, industry and research are collected for temporary storage by NUCLECO or other private operators.

Work has been carried out on ultimate disposal, but no political decision has been taken and priority is being given to the realisation of a centralised interim storage facility.

RESPONSIBILITIES

In January 1994 the Italian Parliament approved a law for the creation of the National Agency for Environmental Protection (ANPA). Under this law, all the tasks and human and financial resources of ENEA/DISP (Directorate for Nuclear Safety and Health Protection) have been moved from ENEA (National Agency for New Technologies, Energy and the Environment) and assigned to ANPA.

ANPA/DISP now oversees the management of radioactive waste, serving as regulator.

ENEL (National Electric Energy Agency) is the government agency responsible for all electric power production. It owns the nuclear power stations and is responsible, under the control of ANPA/DISP, for treatment, conditioning and temporary storage of radioactive wastes produced by nuclear power plants, including spent fuel.

ENEA is responsible for R&D activities on radioactive waste management (treatment, conditioning, and characterisation of waste forms) and for disposal (site selection, characterisation and implementation).

NUCLECO SpA is a company owned by ENI and ENEA, supplying services for collection, storage, treatment and conditioning of low- and medium-level wastes.

STORAGE

Most of the radioactive inventory in Italy (apart from spent fuel) is in the high-level waste stream from experimental reprocessing activities at the ENEA EUREX plant. This is stored in liquid form in stainless steel tanks. Different options for its solidification are being examined.

Short-lived low- and medium-level wastes are stored, mainly at the production sites, awaiting the development of disposal facilities. Most of them remain to be treated and conditioned.

High-level and other long-lived wastes, coming from reprocessing abroad and from the domestic treatment of wastes from the closed ENEA fuel cycle experimental facilities, need to be stored in an engineered facility before their final disposal. This may be located at the same site as the nuclear plant of origin or, preferably, in a central interim storage site.

Spent fuel, apart from that already sent abroad for reprocessing, is stored in cooling ponds at the reactor sites. The two options being examined are reprocessing abroad or long-term interim storage in Italy pending final disposal.

DISPOSAL

During the 1970s and 1980s ENEA carried out several studies on deep geological disposal of high-level and other long-lived wastes. Clay was selected as the reference geological formation and studies performed on different clay formations in various parts of Italy.

Performance assessments were also carried out, including participation in the EC PAGIS study. Work is continuing under EC Cost Shared Actions.

Parallel investigations have been done on the final disposal of low- and short-lived medium-level wastes. At the end of these studies, a list of possible sites for the construction of a national repository was sent by ENEA to the Ministry of Industry.

JAPAN

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

Nuclear energy provided 30.1% of Japan's electricity in 1994. Nuclear power generation capacity totalled 41.4 GW (50 units including a prototype advanced thermal reactor) in September 1995. Four reactors with a capacity of 4.2 GW are under construction.

Spent fuel is being reprocessed in France and the U.K. and at Tokai; further reprocessing capacity is under construction. Waste resulting from reprocessing abroad is being returned to Japan for storage and disposal.

NATIONAL WASTE MANAGEMENT STRATEGY

Low-level wastes are disposed of in the near-surface facility at Rokkasho-mura.

Vitrified wastes resulting from reprocessing are stored for 30-50 years for cooling, before disposal deep underground.

RESPONSIBILITIES

The Government is responsible for establishing safety criteria, guidelines and regulations for the shallow land disposal of low-level wastes. The waste producers are responsible for carrying out and funding such disposals.

For high-level wastes:

- the Government takes overall responsibility for appropriate and steady implementation of the disposal programme as well as enacting any laws or policies required in this connection;
- the Power Reactor and Nuclear Fuel Development Corporation is required to conduct research and development for geological disposal and make geological environmental surveys;

- the electricity utilities are required to secure the funds for disposal and to take responsibility for the necessary research and development.

STORAGE

Spent fuel is stored in ponds at the nuclear power plants and at the reprocessing plants.

Liquid high-level wastes are stored at the Tokai reprocessing plant, awaiting the start-up of the vitrification plant. Facilities for the storage of returned reprocessing wastes and for spent fuel awaiting reprocessing are being constructed at Rokkasho-mura.

Low-level and transuranic wastes are stored at the sites where they are produced.

DISPOSAL

A shallow burial repository for low-level wastes began operation at Rokkasho-mura in 1992. Wastes are confined by a combination of engineered and natural barriers. The final planned capacity of the repository is 600 000 m^3. A repository for extremely low-level radioactive waste, mainly 2200 t of concrete waste from the dismantling of JPDR, is going through licensing procedures.

For high-level wastes, the national policy published in 1992 requires an organisation to be set up with responsibilities for site investigation, selection and characterisation and for demonstrating disposal technology at the candidate site.

Experiments have been carried out in several locations with varying geological environments. An underground laboratory is to be built at Horonobe, though this will not be the final repository site. A repository is scheduled to start operation in the 2030s, or in the mid-2040s at the latest.

KOREA

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

Nuclear energy provides 36.3% of Korea's electricity (1995), from 10 reactors with an installed capacity of 8.6 GW. Six reactors with a capacity of 5.1 GW are under construction.

Spent fuel is stored at the power stations prior to the construction of central interim storage facilities.

NATIONAL WASTE MANAGEMENT STRATEGY

Low- and medium-level wastes are to be disposed of in a rock-cavern-type of repository on a coastal area or on an island.

Spent fuel is to be stored in a central interim storage facility.

RESPONSIBILITIES

The Atomic Energy Commission (AEC) is Korea's top policy-making body on nuclear matters. The Ministry of Science and Technology (MOST) is responsible for nuclear R&D, nuclear safety, and the management of the radioactive waste fund. The Korea Institute of Nuclear Safety (KINS) technically supports MOST in licensing by performing safety assessment review and inspections on nuclear facilities. The Ministry of Trade, Industry and Energy supervises the construction and operation of nuclear power plants.

The Korea Atomic Energy Research Institute (KAERI) is assigned to work on all nuclear related R&D activities and its subsidiary, the Nuclear Environment Management Center (NEMAC), has been designated to carry out the national radioactive waste management programme.

Funding for waste management is through a levy on the electrical utility, based on the amount of electricity generated from nuclear power plants, and on other waste producers, based on waste category and volume.

STORAGE

Operational wastes are stored in surface facilities at sites of nuclear facilities.

Spent fuel is stored in pools or in dry concrete canisters at reactor sites.

The method of storage (wet or dry), the storage capacity and the target date for a central interim storage facility of spent fuel are to be reevaluated.

DISPOSAL

Guleop Island has been designated as a candidate site for disposal of low-level radioactive wastes. The site investigation activities at the island started very recently. A final decision for suitability of the repository site will be concluded by the results from the investigation.

Research is being carried out on safety assessment technologies and on structural behaviour, geological and hydrogeological characteristics related to the proposed rock cavern repository.

There have been no moves to establish disposal facilities for spent fuel, which is to be held in a central interim store.

MEXICO

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

Nuclear energy provides 3.1% of electricity in Mexico (1994), from two reactors on the same site with an installed capacity of 654 MW each. The second reactor came into operation in April 1995.

Spent fuel is being stored at the power station, pending decisions on the future development of the Mexican nuclear power industry.

NATIONAL WASTE MANAGEMENT STRATEGY

A permanent repository is to be developed for all low- and medium-level wastes, including those from medical and industrial activities.

The long-term strategy for spent fuel management remains to be decided.

RESPONSIBILITIES

The Federal Electricity Commission (CFE) is the state-owned national electricity utility and is the only entity that can utilise nuclear materials to generate nuclear power. It is responsible for managing the radioactive wastes from its operations.

The Secretariat of Energy (SE) is responsible for regulatory activities through its subsidiary body, the National Commission of Nuclear Safety and Safeguards (CNSNS).

SE is responsible for policies and contracts regarding radioactive waste management. It has delegated some of its responsibilities to CFE and the National Nuclear Research Institute (ININ).

CNSNS is a specialised technical body in charge of regulating nuclear and radiological safety, physical security and safeguards for all nuclear facilities in Mexico.

ININ and the Institute of Electrical Research (IIE) carry out nuclear research and development.

STORAGE

ININ manages an interim repository for all low- and medium-level waste produced in medical and industrial radioisotope applications. Low- and medium-level wastes from nuclear generation are stored at the reactor site pending the development of a disposal facility.

Spent fuel is stored in cooling ponds at the reactor site pending decisions about future management strategy. The pools have been re-racked to increase the original capacity, in order to accommodate all the spent fuel that the reactors will produce during their expected operating life.

DISPOSAL

Detailed studies are under way in order to determine the engineering design basis for a “triple-barrier” repository, using a French approach. This is planned to have capacity for low- and medium-level wastes generated during the operating life of at least four nuclear reactor units, and could also include the wastes from medical and industrial sources.

Decisions remain to be taken on the final disposal of spent fuel.

NETHERLANDS

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

Nuclear energy provides 5.1% of electricity in the Netherlands (1994) from two reactors with an installed capacity of 0.5 GW.

Spent fuel from the existing nuclear power plants is being reprocessed abroad, with the resulting wastes returned. For possible future nuclear power plants, the question of whether or not to reprocess has been left open.

NATIONAL WASTE MANAGEMENT STRATEGY

Government policy on radioactive waste is based on the 1984 Report on Radioactive Waste, which contains two basic starting points. The first is temporary storage of all radioactive wastes produced in the Netherlands. The second is the Government policy of research into the possibilities of the permanent disposal of such wastes. The first of these two approaches has led to the establishment of the Central Organisation for Radioactive Waste (COVRA) at Borsele; the second has led to the research programme of underground disposal. In addition to incorporating these programmes into an international framework, the government policy is also aimed at concluding international agreements governing the conditions and provisions attached to temporary storage and/or definitive disposal, wherever possible.

Government policy is to create facilities for the long-term storage of all highly toxic wastes that will allow retrieval of the wastes. All radioactive wastes are therefore to be stored centrally, for a period of between 50 and 100 years.

An important part of the Government's radioactive waste policy is the role of the international organisations. The main thrust of the activities lies in the exchange of information on, and the coordination of, national research programmes. As well as actively participating in the various consultative fora, the Netherlands, together with other countries, is also studying possibilities for developing international disposal facilities. So far, however, these initiatives have not produced any concrete results. Nevertheless, the Netherlands' participation in the various international consultative fora has made a major contribution to the development of its national policy.

RESPONSIBILITIES

The national radioactive waste company COVRA is responsible for all kinds of nuclear wastes. 90% of the shares in COVRA are held by the main waste producers, and 10% by the State. Decisions are taken on unanimity, which means that every Shareholder including the State has the right to veto the decisions due to be taken.

The Integral National Research Programme on Nuclear Waste (ILONA) was set up to carry out research on the possibilities for the permanent disposal of radioactive waste. A Programme for Disposal on Land (OPLA) was set up under ILONA in 1985 to study disposal in salt formations. The first phase of the study concluded that permanent disposal in rock salt was technically feasible and in all probability could be accomplished safely. However the results of this study did not totally cover the Government's requirement of retrievability. Although there was, from a scientific point of view, no reason not to proceed to the next phase of the OPLA programme, it was decided that first a more generic programme should be started in which, among other subjects, emphasis should be given to research on the various aspects and possibilities of retrievable storage (including the economic aspects).

STORAGE

COVRA operates a centralised treatment and storage facility for low- and medium-level radioactive waste at the industrial area Vlissingen-Oost in the south-western part of the country. Low- and medium-level waste from all producers in the country is shipped by COVRA to this facility. After treatment, the conditioned waste product is stored in storage buildings for a period of 50 to 100 years.

Storage for low- and medium-level wastes is in a building with three modules each of 5000 m^3 capacity. The building can be extended with a fourth storage module. For further expansion, four buildings with four storage modules each could be constructed on the site. The total storage capacity will then be 80 000 m^3.

In addition to these storage buildings, four other storage buildings with a total capacity of 110 000 m^3 are foreseen to store depleted uranium and solid waste materials with a relatively high concentration of natural radionuclides which are produced in the ore-processing industry.

For the handling and storage of high-level waste, mainly resulting from reprocessing of spent fuel, the construction of a naturally cooled storage vault is planned. This should be ready to receive high-level waste by the year 2000.

DISPOSAL

While the option of disposal of radioactive waste is not currently being pursued, work is continuing on a number of topics, including:

- research into retrievable disposal methods, both under and on the surface, and comparisons of these various in terms of safety and in relation to the policy criteria contained in the "isolation, control, surveillance" concept;
- updating the instruments and database developed under the OPLA programme;
- examining to what extent there may be other possibilities, in addition to long-term disposal and transmutation, for processing or binding radioactive wastes in such a way as to eliminate the risks of radiation.

SPAIN

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

Nuclear energy provides 33.8% of Spain's electricity, from nine reactors with an installed capacity of 7.4 GW (1994).

Spent fuel is stored at the power stations. Fuel from the Vandellos 1 station, now shut down, is being reprocessed abroad and the resulting high-level waste will be returned to Spain. The reprocessing option is not currently being contemplated for the current power stations, and additional storage capacity is being planned, either at the power stations or at a central site, to allow about 40 years of interim storage of spent fuel before disposal.

NATIONAL WASTE MANAGEMENT STRATEGY

Low- and medium-level wastes are being disposed of at the near-surface repository at El Cabril.

Spent fuel and vitrified high-level wastes will be disposed of deep underground.

RESPONSIBILITIES

The national radioactive waste company ENRESA is responsible for all activities related to the management of radioactive wastes, including spent fuel.

The Ministry for Industry and Energy (MIE) plays a major role in the control of nuclear activities, granting the necessary licenses and authorisations, although other ministries or competent bodies are also involved. The Nuclear Safety Council (CSN) is the competent body in matters of nuclear safety and radiological protection.

A public institution, CIEMAT, is responsible for research and development activities in the nuclear field, among others, and provides technical support for ENRESA, CSN and MIE.

The costs of waste management are financed by those responsible for producing the wastes. For nuclear power wastes, a fee is established, based on a percentage of total electricity sales. For other producers, payment is by a tariff applied when the wastes are actually removed.

STORAGE

Most low- and medium-level wastes are temporarily being stored at the sites where they arise until they are sent to the El Cabril disposal facility. Some conditioned wastes were stored in the past at a central temporary storage facility at El Cabril, in reinforced concrete bays.

Spent fuel is being stored in pools at the power station sites. Additional capacity is being provided by changing the fuel storage racks. Storage capacity may be further increased by means of metal casks or by the construction of a central interim storage facility.

DISPOSAL

A repository for low- and medium level wastes is in operation at El Cabril. The concept is based on near-surface disposal with engineered barriers. The facility consists of 28 concrete vaults, each of which will accommodate 320 concrete containers. Each container is in the form of a square concrete box with a capacity for 18 waste drums, the voids being filled with cement mortar. When each vault is filled it will be covered by a reinforced concrete slab. After the operational phase is over, the disposal structures will be covered by a long-term cover.

The siting process for the deep geological repository for spent fuel and other high-level wastes covers studies in granite, salt and clay. A final choice of the general location will be made by the year 2000. The intention is to start construction in 2015 and for the repository to be operational in 2020.

Non-site specific conceptual repository designs have been developed. In the salt concept, wastes in self-shielding casks would be placed in drifts excavated at a depth of 850 m in a bedded salt formation. In the granite concept, wastes in steel canisters, embedded in a thick layer of swelling clay, would be placed in drifts excavated at a depth of 500 m. A design for a repository in clay is under development.

SWEDEN

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

Nuclear energy provides 51% (1994) of Sweden's electricity, from 12 reactors with an installed capacity of 10 GW.

Some 140 t of spent fuel from past operations has been shipped for reprocessing abroad. All spent fuel is now stored at the power stations for about one to five years, and then transported to a central storage facility (CLAB) for storage for 30-40 years before disposal.

NATIONAL WASTE MANAGEMENT STRATEGY

Operational wastes (low- and medium-level, short-lived) are being disposed of at the final repository, SFR, at Forsmark.

Spent fuel and long-lived radioactive residues will be disposed of deep underground, after a period of interim storage.

RESPONSIBILITIES

The waste management responsibilities of the nuclear utilities are handled by their jointly owned company, the Swedish Nuclear Fuel and Waste Management Company, SKB.

The SKB programme is reviewed every three years by the Swedish Nuclear Power Inspectorate, SKI, which forwards the programme and their review report to the Government for decision.

Licenses for the construction and operation of waste management facilities including repositories are granted by the Government, on the basis of reviews and recommendations from the SKI and the Swedish Radiation Protection Institute.

Funding to cover the costs of spent fuel management is collected by SKI, based on a charge per unit of nuclear electricity produced. The dues are deposited at the National Bank of Sweden and SKB is reimbursed from this fund. Costs for the management and disposal of operating wastes are borne directly by the utilities.

STORAGE

Spent fuel is stored in pools at reactor sites for about one to five years, followed by central interim storage for 30 to 40 years. Operating wastes are disposed of as soon as possible after they are produced.

The central storage facility for spent fuel, CLAB, is located next to the Oskarshamn nuclear power station. It consists of an above-ground receiving and handling facility and an underground, man-made rock cavern, about 30 m below the surface. The spent fuel is stored under water in stainless-steel-lined concrete pools.

DISPOSAL

The final repository for low- and medium-level wastes, SFR at Forsmark is constructed in bedrock under the Baltic, with a rock cover of about 60 m. It has various caverns for different waste categories. The waste containing most of the radionuclides is disposed of in a large concrete silo in a 70-m high cylindrical rock cavern. Rock caverns 160 m long are used for the rest of the wastes. Various types of backfill, buffer and seal will be used; the most extensive being in the silo repository where the waste packages will be backfilled with concrete and the silo is surrounded by a clay barrier. When the silo is filled a concrete lid will be cast on top. The buffer will be completed with a layer of sand and bentonite clay over the lid. The space above will be backfilled with sand.

A repository for spent fuel will be constructed at a depth of about 500 m in Precambrian crystalline rock. The fuel will be encapsulated in copper canisters with an inner steel container, placed in boreholes and surrounded by highly compacted bentonite. The repository tunnels will be backfilled with a mixture of sand and bentonite or a similar mixture, and the main tunnels and shafts will be plugged.

The spent fuel elements stored in the CLAB facility will be encapsulated in canisters in a special facility before disposal. An encapsulation plant is planned to be built in connection to CLAB. The aim is to start the licensing procedure for the plant in 1997.

Geological investigations started in the mid-1970s and about 15 different study sites have since been investigated by surface, and in many cases, also borehole measurements. These investigations indicate that many sites are technically feasible for hosting a repository. Feasibility studies for a deep repository will be performed in 5-10 municipalities in Sweden followed by geological site investigations in two of these municipalities. The aim is to select one site for detailed characterisation starting a couple of years after 2000. In preparation for the site characterisation and for the repository construction SKB has constructed the Äspö Hard Rock Laboratory, located near the Oskarshamn nuclear power plant. The laboratory consists of a tunnel of 3.6 km down to a depth of 460 m, and associated facilities.

The aim of the activities performed at Äspö is to evaluate investigation methods, to demonstrate tools for design, planning and construction of a repository and to collect data for safety analyses.

The target for start of disposal of encapsulated spent fuel is 2008. The repository is planned to be commissioned in two phases with only up to 800 t (uranium weight) disposed of in the first phase. The first phase should be followed by a thorough evaluation of all pertinent experiences (including the possibility of waste retrieval) before deciding to proceed with the second phase.

SWITZERLAND

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

Nuclear energy provides 36.7% of Switzerland's electricity, from five reactors with an installed capacity of 3.1 GW (1994).

Spent fuel is reprocessed abroad, and the resulting wastes are returned to Switzerland for interim storage and disposal. The option of disposing of non-reprocessed fuel is being kept open. The minimum interim storage period for high-level waste is planned to be 40 years.

NATIONAL WASTE MANAGEMENT STRATEGY

All radioactive waste are to be disposed of in repositories in suitable geological formations. Two repository types are envisaged, one primarily for short-lived wastes and one for high-level and long-lived medium-level wastes.

RESPONSIBILITIES

The producers of radioactive wastes of all categories are responsible for their safe management.

The National Co-operative for the Disposal of Radioactive Waste, NAGRA, was formed by the electricity utilities involved in nuclear power and the Swiss Confederation, which is responsible for the wastes from medicine, industry and research. NAGRA is responsible for preparation of projects for final disposal and possible final conditioning of the wastes, as well as for the preceding controls.

For construction and operation of repositories, special companies are formed. The first of these, the Co-operative for Nuclear Waste Management, Wellenberg (GNW), was established in June 1994 to implement the low- and medium-level waste repository planned in the Canton Nidwalden in Central Switzerland.

The responsibility for spent fuel reprocessing, and transport, waste conditioning and interim storage remains with the utilities. For centralised interim storage a special company, ZWILAG, was founded to construct and operate the facilities.

The Federal Government is supported in its decisions on waste management by a number of federal agencies, other federal offices, and scientific institutions.

The costs of waste management are borne directly by the producers. The contributions from the electricity utilities at present are linked to the nuclear power production capacity; the contributions from the Swiss Confederation are calculated for a virtual “power equivalent”. Project costs are paid directly by the producers; there is no State organisation for collecting and redistributing funds for repository implementation.

STORAGE

Spent fuel is stored in pools at the power stations until it is transported abroad for reprocessing. Returned reprocessing wastes will be stored in a central interim storage facility.

A project for a central facility has been submitted by ZWILAG to the Government. It is intended to use dry storage for fuel elements or high-level wastes in transport containers in a surface hall. Low- and medium-level wastes will be stored in separate surface halls or else co-located. A site has been chosen at Würenlingen and a general licence has been granted by Parliament.

Storage capacity for interim storage of spent fuel and high-level wastes will be sufficient for the current nuclear power plants.

DISPOSAL

The reference repository concept selected for short-lived low- and medium-level wastes is a mined cavern system with access through horizontal tunnels. Safety studies have confirmed the acceptability of this concept. One hundred potential sites were evaluated during 1978-81. Twenty sites were selected for additional evaluations, which were carried out in 1982-83. Subsequently, four sites were identified for detailed investigations, and Wellenberg was selected as the “preferred” site in 1993. A general licence application was submitted by GNW in June 1994. The local community at the Wellenberg site has voted in favour of the repository project. However, a referendum in June 1995 at the cantonal level led to a narrow majority (2%) of opponents to the project. The technical, legal and political ramifications of this decision are currently (1995) being reviewed by the governmental authorities and by NAGRA and GNW.

The reference design envisages wastes solidified in cement, bitumen or polymers, waste drums possibly grouted into a concrete container, backfilling of the remaining empty spaces with special concrete, concrete lining of the disposal caverns and sealing of access tunnels on final closure. The wastes may be divided into several toxicity classes, with appropriate combinations of barriers for each class.

The reference repository concept for high-level and transuranic wastes is a system of mined tunnels and silos at a depth of about 1200 m in crystalline basement rock or 500 to 800 m in clay. Vitrified high-level wastes would be surrounded by a corrosion-resistant steel canister, a layer of highly compacted bentonite clay, and, finally, the host rock and its overburden. The transuranic waste would be embedded in a leach- and dissolution-resistant solidification matrix and emplaced in a cylindrical concrete silo surrounded with special concrete. The spaces between the filled concrete silo and the rock wall of the cavern would be backfilled with bentonite. The final design will depend on the rock type and site selected. Site investigations have been concerned with regions for potential sites; the next phase of investigations involves field work in both crystalline and clay formations. In November 1994 applications for geologic investigations at two specific sites were submitted by NAGRA to the government. Repository construction, or alternatively participation in an international project, is planned for some time after 2020.

An extensive research programme has been under way at the Grimsel underground rock laboratory since 1984, involving co-operative projects with other countries since 1991.

UNITED KINGDOM

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

Nuclear energy provides 26.9 per cent of the United Kingdom's electricity, from 34 reactors with an installed capacity of 11.9 GW (1994). A new reactor with a capacity of 1.2 GW started operation in 1995.

Spent fuel is stored in ponds at power station sites; at the Wylfa station air-cooled storage is used. Spent fuel awaiting reprocessing is stored in ponds at Sellafield

NATIONAL WASTE MANAGEMENT POLICY

Solid low-level wastes are being disposed of in near-surface facilities at Drigg and Dounreay. An underground deep disposal facility for stocks and future arisings of medium-level wastes and selected low-level wastes is to be developed.

High-level (heat-generating) wastes from fuel reprocessing will be stored, normally in vitrified form, for at least 50 years. Wastes from the reprocessing of fuel from BNFL's overseas customers will be returned to the country of origin.

The final conclusions of a review of the United Kingdom radioactive waste management policy were published in a White Paper in July 1995. Existing disposal strategies for intermediate and low-level waste were confirmed. For high-level waste, the White Paper identified disposal to geological formations on land as the favoured option for the long term, once the waste has been allowed to cool, and the Government is initiating work on a research strategy for the disposal of high-level waste and spent fuel.

Wastes arising from reprocessing foreign spent fuel should continue to be returned to their country of origin, but for low-level waste and intermediate-level waste this can be achieved by substituting a radiologically equivalent amount of high-level waste in a manner which achieves broad environmental neutrality for the United Kingdom, subject to a disposal route for the substituted wastes being established.

RESPONSIBILITIES

Policy is set by the Secretaries of State for the Environment, Scotland and Wales, who may refer matters to the Radioactive Waste Management Advisory Committee for advice. The National Radiological Protection Board provides information and advice on the radiological aspects of waste management standards. Her Majesty's Inspectorate of Pollution (HMIP), or its Scottish equivalent, is the organisation having the primary responsibility for ensuring compliance with the national policy for radioactive waste management. The Health and Safety Executive (HSE) regulates nuclear safety and the accumulation of radioactive waste on nuclear licensed sites. HSE and HMIP cooperate to ensure that the national waste management policy is implemented.

The owners of spent fuel are responsible for its safe management, including whether or not to reprocess it.

The producers of radioactive wastes are responsible for their safe management, including meeting all associated costs. The industry has established UK Nirex Ltd. to develop a facility for low- and medium-level (but not high-level) wastes, and holds its ordinary shares. The Government holds one Special Share.

STORAGE AND DISPOSAL

Low-level wastes are currently stored for the minimum practical period before being disposed of.

Low-level wastes are disposed of mainly at BNFL's Drigg facility, although UKAEA disposes of low-level wastes arising at Dounreay at facilities there.

The Drigg facility near Sellafield has been the principal site for low-level waste disposal since 1959. For many years wastes were placed directly into trenches cut into a clay layer within the glacial sediments, with capping to reduce water ingress. Since 1989 compacted and grouted wastes contained in drums or boxes have been placed in concrete-lined vaults which will be capped when filled.

Medium-level wastes are currently stored, mainly at the sites of production, awaiting disposal in UK Nirex's planned deep disposal facility. HSE regulates such storage to ensure its safety. UK Nirex is currently investigating a site near to BNFL's Sellafield Works for its proposed deep disposal facility for medium- and low-level wastes. It plans to excavate a series of caverns in volcanic rock over 650 m below ground level, into which the conditioned wastes will be emplaced. Its next step is to develop a Rock Characterisation Facility in the proposed strata to demonstrate their suitability for the facility. This is currently the subject of a planning enquiry.

High-level wastes are stored before vitrification. The vitrified wastes will be stored for at least 50 years, to allow them to cool, before being disposed of in a suitable facility. Storage and vitrification are currently being carried out by BNFL in the Vitrification Plant which the Company opened in 1991.

UNITED STATES

NUCLEAR ENERGY AND SPENT FUEL MANAGEMENT

Nuclear energy provides 19.6% of electricity in the U.S.A., from 109 reactors with an installed capacity of 99 GW (1994). One reactor with a capacity of 1 GW is under construction.

Spent fuel is not currently being reprocessed. Spent fuel, and the high-level wastes resulting from past reprocessing activities, will continue to be stored, at the power stations, the reprocessing plants, and possibly at central storage sites, pending the development of disposal facilities.

NATIONAL WASTE MANAGEMENT STRATEGY

Three categories of waste are defined: low-level, transuranic and high-level. Transuranic wastes are wastes contaminated with long-lived radionuclides such as uranium and plutonium. High-level wastes include spent fuel and heat-generating wastes from reprocessing.

Low-level waste disposal remains the responsibility of each State within which the waste arises. Several shallow land burial sites are currently in use.

Systems for the disposal of transuranic and high-level wastes are to be developed by the U.S. Department of Energy.

A Monitored Retrievable Storage (MRS) facility is authorised for interim storage of spent fuel, but a site remains to be identified.

RESPONSIBILITIES

The storage and disposal of most commercially generated low-level wastes is the responsibility of the States in which they are generated. Many States have formed interstate agreements in order to share disposal responsibilities. All other wastes are the responsibility of the Federal Government. The generators are responsible for the storage of commercial spent fuel and high-level wastes until the Federal Government takes title to such wastes in 1998.

The federal agencies involved include the Department of Energy (DOE), responsible for storage and disposal, the Nuclear Regulatory Commission (NRC), responsible for regulation and licensing, and the Environmental Protection Agency (EPA), responsible for protection standards.

For spent fuel and high-level wastes, the owners and generators pay the full costs of disposal, and a National Waste Fund has been set up to cover the costs of the civil waste management programme. The fund receives revenue from all those planning to use the repositories. An adjustable fee is charged to utilities, based on the amount of nuclear electricity generated. For low-level wastes, the generators provide funding from their operating budgets.

STORAGE

Commercial low-level wastes are stored on the sites where they arise until enough waste is available for a shipment to a disposal site. The failure to provide disposal capacity is increasing the need for on-site storage. Facilities in use include permanent buildings designed specifically for the extended storage of such wastes, shielded concrete storage modules or bunkers, and shielded storage casks.

Transuranic wastes are held in temporary stores pending the development of disposal sites. Storage methods include retrievable burial, below-ground bunkers, concrete caissons, ground-level concrete pads, and buildings.

Most spent fuel is stored at power station sites in pools, although as pool storage capacity limits are being reached, increased use is being made of dry storage, in concrete modules, concrete or metal casks, and modular vaults.

Several technologies are being considered for the proposed central MRS facility, including pools, dry vaults, multi-element sealed canisters in concrete modules, metal dual-purpose storage and transport casks, and concrete casks. Several of these design concepts have either been licensed by the NRC or are in the process of being licensed.

High-level wastes are being stored in liquid form at DOE facilities at Hanford, Idaho National Engineering Laboratory and Savannah River. These wastes will be vitrified in facilities now under construction and stored pending the availability of disposal facilities.

DISPOSAL

Seven shallow-land disposal facilities for commercial low-level wastes have been operated, of which five are no longer in use. They consist of excavated trenches, in some cases with a 5-m soil cover or an engineered cover such as concrete. Several alternative concepts are now being considered by the States, such as below-ground vaults and earth-mounded concrete bunkers. Future facilities are likely to incorporate engineered barriers to a greater extent than do currently operating facilities. There are currently eleven inter-State compacts, and six States have opted to go it alone. Three sites are either at the characterisation or at the licensing stage, in California, North Carolina and Texas.

The DOE has six facilities for the disposal of its low-level wastes, at Savannah River, Oak Ridge, the Nevada Test Site, Los Alamos, Idaho National Engineering Laboratory, and Hanford. Designs include shallow-burial trenches, below-ground vaults, tumuli, above-ground vaults and deep shaft burial.

A Waste Isolation Pilot Plant (WIPP) has been constructed near Carlsbad, New Mexico. WIPP is intended for the disposal of DOE-generated transuranic wastes. The wastes, contained in drums or boxes, are disposed of in a 2000-ft thick salt formation, 2150 ft below the surface, with access via four shafts. There are currently over 10 miles of tunnels constructed, but most of the repository area remains undisturbed awaiting transuranic wastes for disposal. A decision regarding WIPP's suitability as a repository will be made when evaluation of the current Test Program is completed.

Yucca Mountain, Nevada, is being characterised by DOE as a potential site for the disposal of spent fuel and high-level wastes, generated commercially and by DOE itself. Construction of an underground Exploratory Studies Facility began in 1993. The current design concept for the repository is for a number of disposal galleries accessed by two ramps and a possible shaft. In the reference design, wastes, suitably packaged, would be placed in vertical holes bored in the floors of the galleries, but other methods, such as emplacement in horizontal boreholes and within the galleries themselves, are also being considered. In the reference design, no buffer material will be used around the waste packages because the waste package is designed to be surrounded by an air gap, but alternatives using a variety of backfills are also being evaluated. If the site is found to be suitable, disposal operations are planned to begin in 2010.