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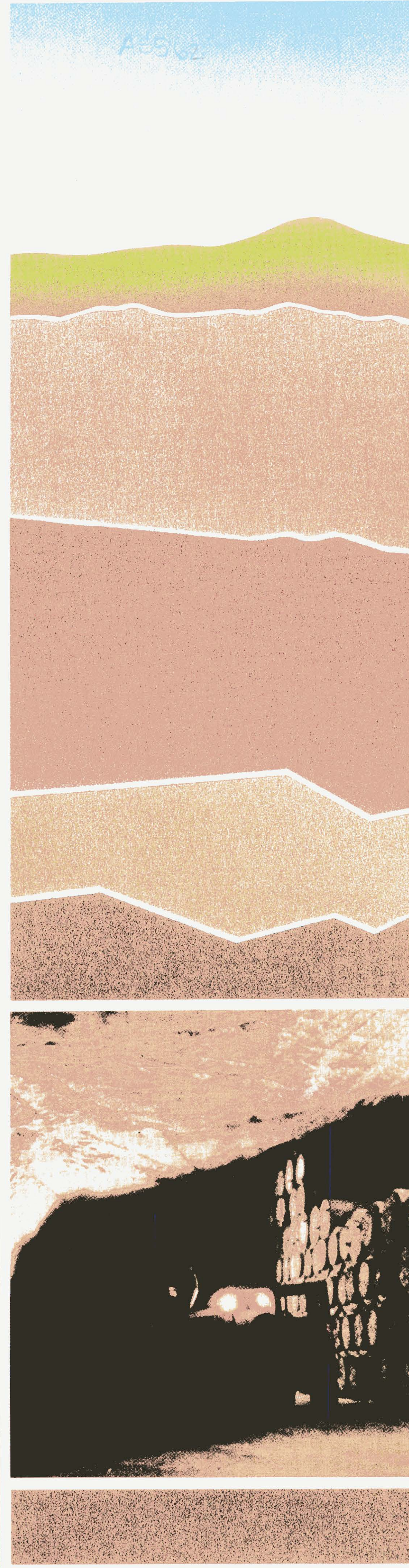

MANAGING RADIOACTIVE WASTE IN THE EUROPEAN COMMUNITY

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INTRODUCTION

Radioactive wastes resulting from nuclear electricity generation and from uses of radiation and radioactive materials in medicine, agriculture, industry and research must be managed and disposed of in ways that ensure the protection of people and the environment, now and in the future.

A Community Plan of Action in the field of radioactive waste management was approved by the Council of the European Communities on 18 February 1980. The plan, which ran from 1980 to 1992, provided 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 waste 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 Council of the European Communities has recently approved the extension of the plan to the year 1999. The renewed plan of action covers all types of radioactive waste and takes into account the context of the Single European Market from 1993 on.

Under the plan, there have been substantial advances in all aspects of the safe management and disposal of all categories of radioactive wastes: those arising from nuclear power, which now provides around one third of the

Who has nuclear power and who stores nuclear waste.

Country	Nuclear power	Low/medium waste	High level waste	Spent fuel
BELGIUM	√	√	√	√
DENMARK		√		
FRANCE	√	√	√	√
GERMANY	√	√	*	√
GREECE		√		
IRELAND		√		
ITALY	√	√	*	√
THE NETHERLANDS	√	√	*	
PORTUGAL		√		
SPAIN	√	√	*	√
UNITED KINGDOM	√	√	√	√

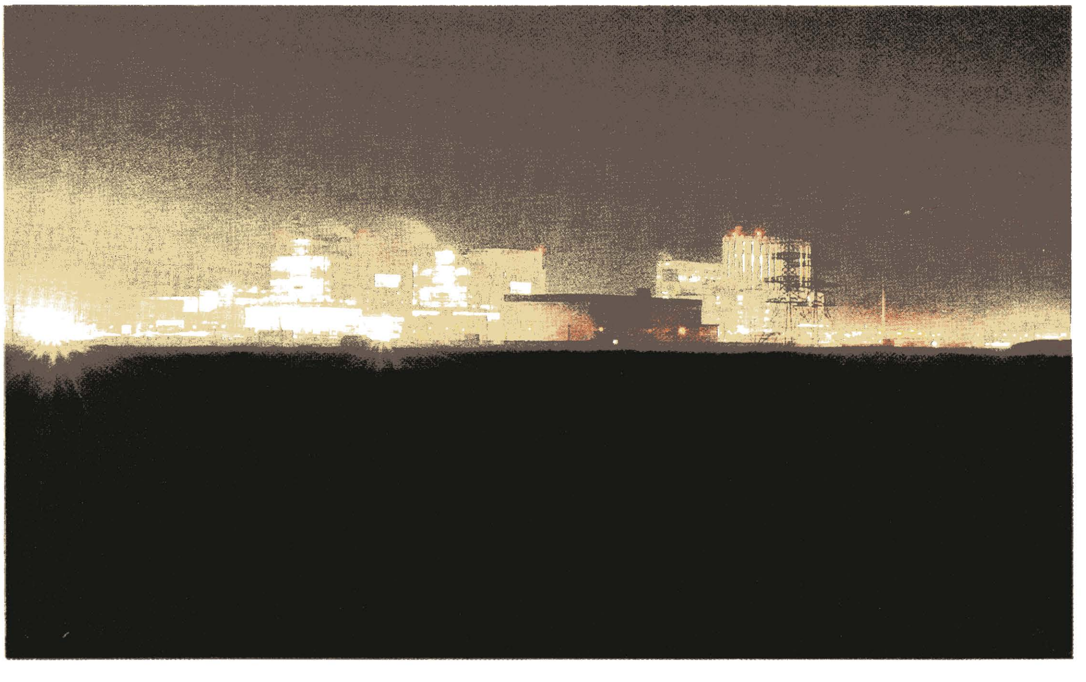
*Planned.

Community's electricity needs; from medical, agricultural, industrial and research sources; and from the mining and processing of naturally radioactive raw materials.

Progress in implementing the plan was reported by the Commission to the Council of Ministers in 1983, 1987 and 1993. In recent years there has been a growing awareness of the need to optimise waste management procedures, for example through reduction of waste volumes, to develop rules for the transport and international transfer of wastes, to deal with wastes from the dismantling of old nuclear installations and to restore sites no longer in use, and to deal with wastes from sources other than nuclear power. These requirements are being addressed in current Commission and national programmes.

Although substantial progress has been achieved in all areas, there remains significant public concern, in the EC and elsewhere, particularly about the disposal of the longer lived wastes.

The aim of this booklet is to seek to address this concern by summarising the present situation relating to radioactive wastes in EC countries and the outlook for the future. It is based on the third report on "Radioactive Waste Management in the European Communities". The remaining chapters describe the sources, categories and quantities of wastes to be dealt with, the international, EC and national regulatory frameworks, the range of techniques being applied or developed for the treatment, transport, storage and disposal of the wastes, the approaches to the assessment of safety, the associated research and development activities, and some related issues, including the costs of waste management and public information and involvement.

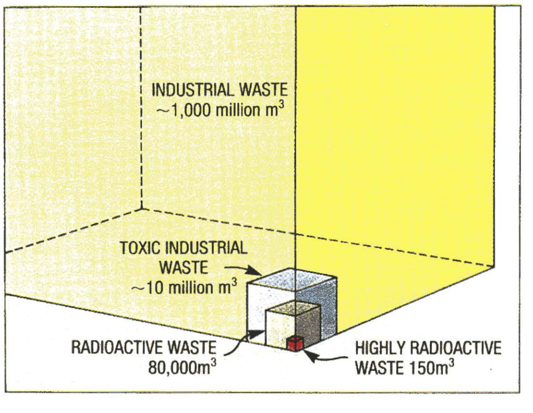


SOURCES, CATEGORIES AND QUANTITIES

All Member States of the European Community produce radioactive wastes. Some, with no nuclear electricity generation, produce only small quantities, which come from various uses of radiation and radioactive materials in medicine, agriculture, industry and research. Those which use nuclear power stations to generate electricity produce much larger amounts. Radioactive wastes from military activities do not come within the scope of this booklet; in those countries that have military nuclear programmes the quantities of such wastes are generally well below the quantities resulting from electricity generation; they are of the same type and are dealt with in similar ways.

In total, the amounts of radioactive waste that have been produced in the EC in the whole period since the start of commercial nuclear electricity generation in the 1950s are small when compared with the amounts of industrial toxic waste produced each year, and very small when compared with the amounts of solid wastes of all types produced each year. The intrinsic harmfulness of radioactive wastes, however, and the level of public concern that exists, have resulted in more highly developed methods of management and regulation and a more precise knowledge of sources and quantities than for any other type of waste. The growing concern about the management of wastes of all kinds is now leading to pressures to apply some of the approaches already established for radioactive wastes to other types of toxic waste. In this chapter we describe the sources, categories and quantities of radioactive waste produced in the EC Member States.

Annual waste production in the EC.



SOURCES

Radioactive wastes can result from three types of activity:

- ☐ nuclear electricity generation, including related research and the decommissioning of obsolete plants;
- ☐ uses of radiation and radioactive materials in medicine, agriculture, industry and research;
- ☐ processing of materials that are naturally radioactive, such as uranium ores and phosphate fertilisers.

CATEGORIES

Because naturally radioactive materials are so widespread, occurring in the earth, in water and in the air, wastes of any type are likely to contain at least some traces of radioactivity and should, strictly speaking, be called radioactive waste. In practice, the term is reserved for wastes that are managed under a special system of control, which involves the notification and registration of any waste produced and the licensing of any installations handling the material.

There are many different radioactive elements, emitting several types of radiation, and therefore many types of radioactive waste, all of which have to be managed in ways that ensure the necessary levels of safety. The different types of waste can, however, be classified into a small number of categories, depending essentially on the concentrations of radioactive material that they contain and the times for which they remain radioactive, with all the wastes in any particular category being managed in the same general way. The classification used in this booklet allows uniform data on the quantities of waste generated in the Member States to be produced and corresponds to a certain extent to current or planned disposal options. Different countries may use slightly different categories, depending on their particular waste management and disposal options.

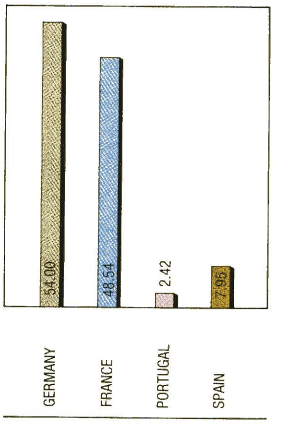
The classifications "low", "medium" and "high" relate to the concentration of the radioactivity in the waste and hence to the intensity of the emitted radiation. In time, high level waste becomes medium level and then low level waste; eventually, as with all radioactive materials, the radioactivity decays to nothing. There is an important distinction between radioactive wastes, which eventually become harmless, albeit in some cases after a very long time, and chemically toxic wastes, some types of which remain toxic for ever.

An important additional category to low, medium and high, produced mainly in the nuclear industry and in associated research activities, is alpha waste. It is so called because it contains radioactive materials that emit alpha particles, a form of radiation that is very easy to shield – most of it will not even penetrate a sheet of paper – but potentially dangerous if emitted inside the body, for example if some alpha emitting material is breathed in or swallowed. Most alpha emitting radioactive materials are very long lived, so they have to be kept isolated for very long periods to ensure safety. They too, however, eventually lose all their radioactivity.

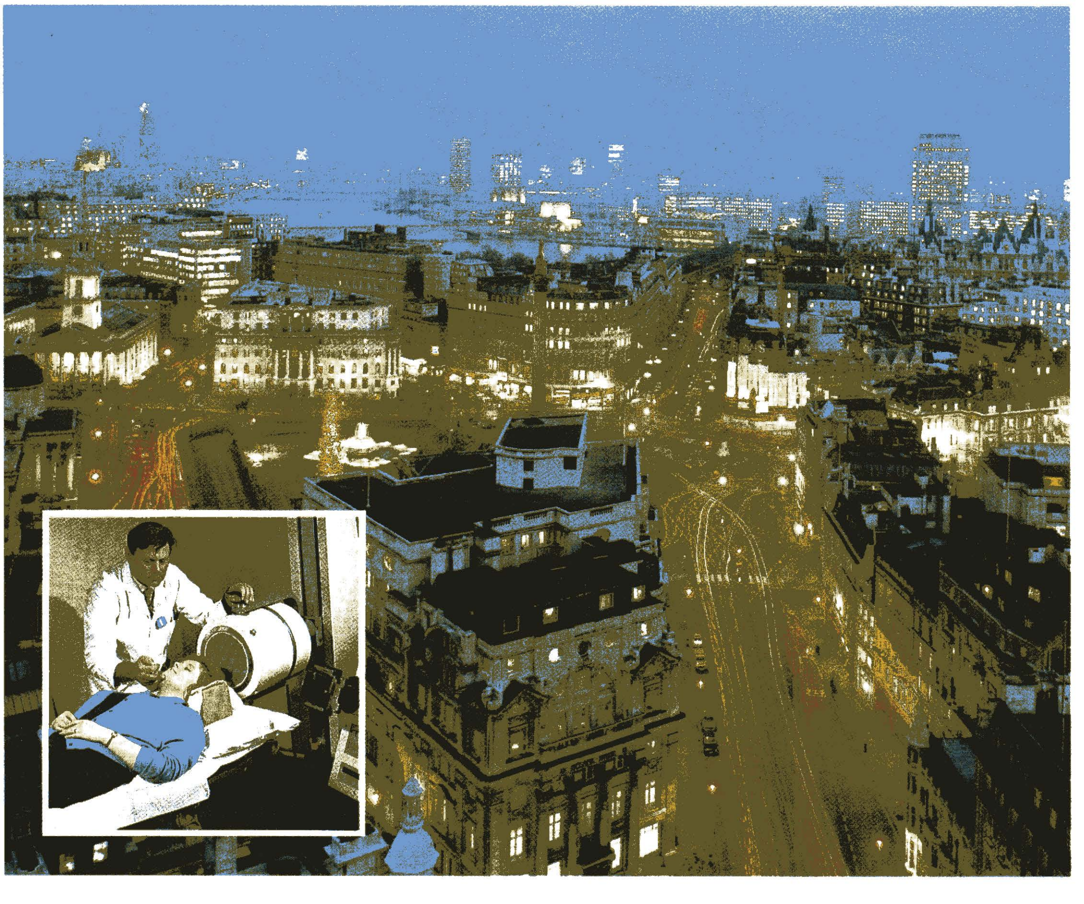
Separate classifications are generally used for the wastes from uranium mining and milling and from sources such as phosphate fertiliser production. These wastes can arise in large volumes and generally contain very low concentrations of naturally occurring radioactive materials, some of which are long lived.

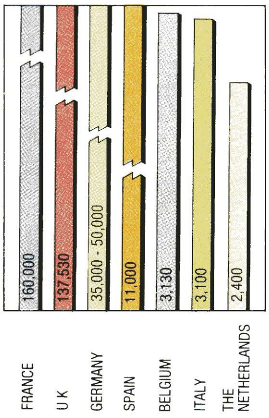
Discharges of liquid and gaseous effluents into surface waters and the atmosphere are another form of radioactive waste. Such discharges are subject to national and EC regulations aimed to ensure that the wastes are diluted to very low concentrations in the environment. The discharges are regularly monitored and reported to the Commission of the European Communities and to the national regulatory bodies and are not further discussed in this booklet.

Some countries have a category of very low level wastes, exempt from most of the regulatory controls applied to other radioactive wastes.

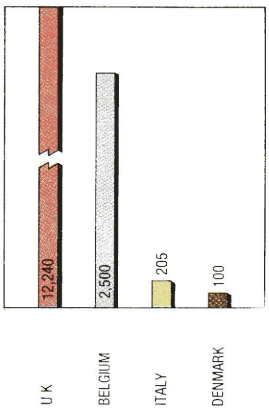


Uranium milling wastes (10^6 tons) accumulated in the EC to the end of 1990.





Production of low level waste treated and conditioned (m³), in various Community Member States, 1991-1995.



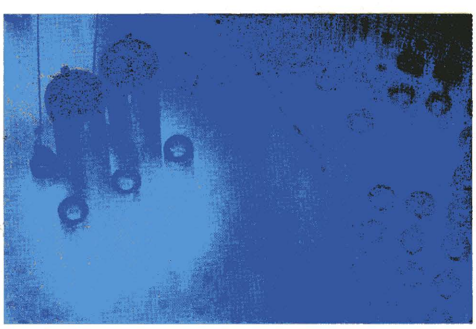
Production of medium level waste treated and conditioned (m³), in various Community Member States, 1991-1995.

Low level waste – waste that contains or is suspected of containing low concentrations of radioactive material. Since it emits so little radiation it needs no special shielding and is handled using simple protection measures such as rubber gloves. It comes from nuclear power stations and other nuclear installations and from research centres, hospitals and industries that use radiation and radioactive materials. Typically it consists of paper towels, used syringes, rubber gloves, overshoes and air cleaning filters.

Medium (or intermediate) level waste – waste that contains higher concentrations of radioactive material than low level waste. It needs shielding, generally metal or concrete, and remote handling devices to protect people from the radiation it emits. It comes from nuclear power stations and reprocessing plants (where used nuclear fuel is chemically treated to remove the waste from the reuseable fuel) and from medical, industrial and research uses of radioactive isotopes, for example for the sterilisation of medical equipment and for cancer therapy. Typically it consists of metal scrap, sludges, resins, and used radioisotope sources.

Alpha waste – low or medium level waste that also contains long lived alpha emitters. It is handled in general in the same way as low or medium level wastes but with special precautions to keep it isolated from people. It comes from some nuclear research laboratories, some nuclear fuel fabrication plants and from reprocessing plants. Typically it is like other low and medium level wastes, but containing alpha emitting materials such as plutonium.

High level waste – waste with the highest concentrations of radioactive material. The intensity of the radiation it emits is so high that the waste becomes physically hot and remains so for many decades, till much of the radioactivity decays away. It needs cooling, heavy shielding and remote handling devices. It comes from reprocessing plants and is the "ash" from the "burning" of nuclear fuel in nuclear power stations. It is initially in liquid form and is subsequently vitrified, that is incorporated in hard, stable blocks of glass. Used nuclear fuel that is not reprocessed is also a high level waste but is classified separately from the high level wastes from reprocessing.



QUANTITIES

The quantities of radioactive wastes that have been disposed of, that are currently in store and that are likely to be produced up to the year 2020 in EC Member States are shown in the tables at the end of this booklet. The figures assume that the wastes have been treated (for example by compaction or incineration) and conditioned (for example by incorporation into cement), using currently available methods.

RADIOACTIVE WASTES FROM NUCLEAR ELECTRICITY GENERATION

About one third of all the electricity used in the European Community is generated in nuclear power stations. Some countries have now been generating electricity in this way for over 30 years. Although more than a million cubic metres have already been disposed of, there is a considerable backlog in stores awaiting disposal, and the development of suitable disposal facilities for this waste would be essential even if nuclear generation were to be phased out. In fact, nuclear generation is likely to continue and possibly increase in a number of countries. The figures for future radioactive wastes from nuclear power programmes refer only to wastes from existing plants (power stations and associated fuel cycle installations) and committed new plants; this might lead to unrealistically low figures at the national level; for example in France, new plants are likely to be added during the period 2000 to 2020.

RADIOACTIVE WASTES FROM MEDICAL, AGRICULTURAL, INDUSTRIAL AND RESEARCH SOURCES

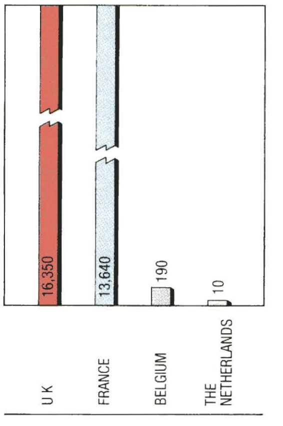
These wastes are mostly low level and short lived. Exceptions are used radioisotope sources, some of which can be very radioactive and some long lived. There are about half a million radioisotope sources in use worldwide, which will eventually have to be safely disposed of. Accidents such as the one in Goiana (Brazil) in 1987 show that some such sources are potentially very dangerous if not properly dealt with.

During the period 1991 to 1995, Germany, France, Italy and the United Kingdom are each expected to produce a total of about 5,000 cubic metres of these types of waste. The corresponding figure for the Netherlands is about 1,600 cubic metres, for Belgium, Denmark, Spain and Greece between 100 and 400 cubic metres each and for Ireland and Portugal below 100 cubic metres each.

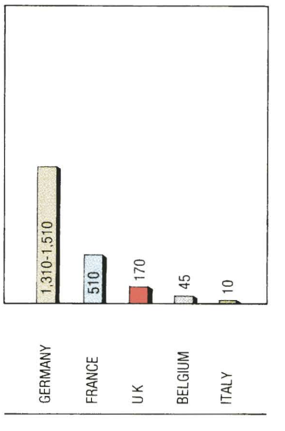
RADIOACTIVE WASTES FROM THE PROCESSING OF NATURALLY RADIOACTIVE RAW MATERIALS

Many raw materials which are processed on a large scale contain low concentrations of naturally radioactive elements. The processing of these materials can result in a concentration of the radioactivity, either in the products or in various waste streams. Examples are the production of artificial phosphate fertilisers and the extraction of oil and gas. No overview of the quantities, compositions, radioactivity levels, etc. of these materials is currently available. An indication of their possible importance can, however, be obtained from the reports of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). The production and use of phosphate fertilisers, for example, results in an annual collective radiation dose worldwide which is over 12 times that from the routine operations of the whole of the world's nuclear power industry (collective dose is a measure of the total radiation exposure of a group of people, in this case the whole of the world's population, from a particular source or group of sources). To put the figures into context, however, phosphate fertilisers and routine nuclear power operations together result in an annual collective dose that is a minute fraction, less than one thousandth, of the total annual collective dose to the world's population from natural sources of radiation.

More information is available on the wastes from uranium mining and milling. Such wastes provide potentially the greatest long term contribution to human exposure from nuclear power, albeit resulting in radiation exposures that are a very small fraction of natural background exposures.



Production of alpha waste treated and conditioned (m^3), in various Community Member States, 1991-1995.



Production of high level waste treated and conditioned (m^3), in various Community Member States, 1991-1995.

REGULATION AND CONTROL

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

Radiation protection dates back to the early years of medical uses of radiation and radioactive materials; various countries introduced protection rules during the first few decades of this century. Since 1928, the International Commission on Radiological Protection (ICRP) has published recommendations, regularly updated in the light of the most recent information on the effects of radiation on health, which form the basis for regulations controlling radiation exposures of people in most countries. ICRP is an independent body of medical and scientific experts.

In addition to its general recommendations, ICRP makes specific recommendations on radiation protection requirements for radioactive waste disposal, as do the International Atomic Energy Agency (IAEA) and the Nuclear Energy Agency (NEA) of the OECD.

These international recommendations form the basis for specific Community regulations, which in turn provide common guidelines and requirements from which most of the national measures are derived. Thus there are three levels of recommendation, regulation and control: international, Community-wide and national. This regulatory framework is summarised in this chapter; more detailed information can be found in the EC report EUR 12570 EN (1989): "Objectives, Standards and Criteria for Radioactive Waste Disposal in the European Community".

General principles.

Field	Principle
Radiation protection	
System of dose limitation	• Justification • Optimisation of protection (ALARA) • Individual dose limitation
System of control	• Notification • Registration • Licensing
Ethical and sociological questions	• Care for others • Public involvement • Polluter should pay • Compensation for damage (civil liability)
Environmental and natural resources protection	• Prevention of damage • Rectification of damage • Protection of natural resources
Nuclear safeguards	• Prevention of nuclear materials diversion

INTERNATIONAL RECOMMENDATIONS AND GUIDANCE

There is a broad international consensus on the principles to be applied to the limitation of exposures of people to radiation, based on the recommendations of the ICRP. The principles are:

- Justification – any practice that involves additional radiation exposure should produce a net benefit.
- Optimisation of protection – all exposures should be kept As Low As Reasonably Achievable (commonly shortened to ALARA), economic and social factors being taken into account.
- Individual dose limitation – individual doses should not exceed specified levels, set on the basis of comparisons between the risks associated with the radiation exposures and other types of risk.

The first principle, the requirement for a net benefit, is not applicable to radioactive waste disposal in itself; benefit comes from energy production and other uses of radioactive materials.

The application of the second principle, ALARA, has almost always resulted in exposures that are below, and usually far below, the individual dose limits set by the third principle.

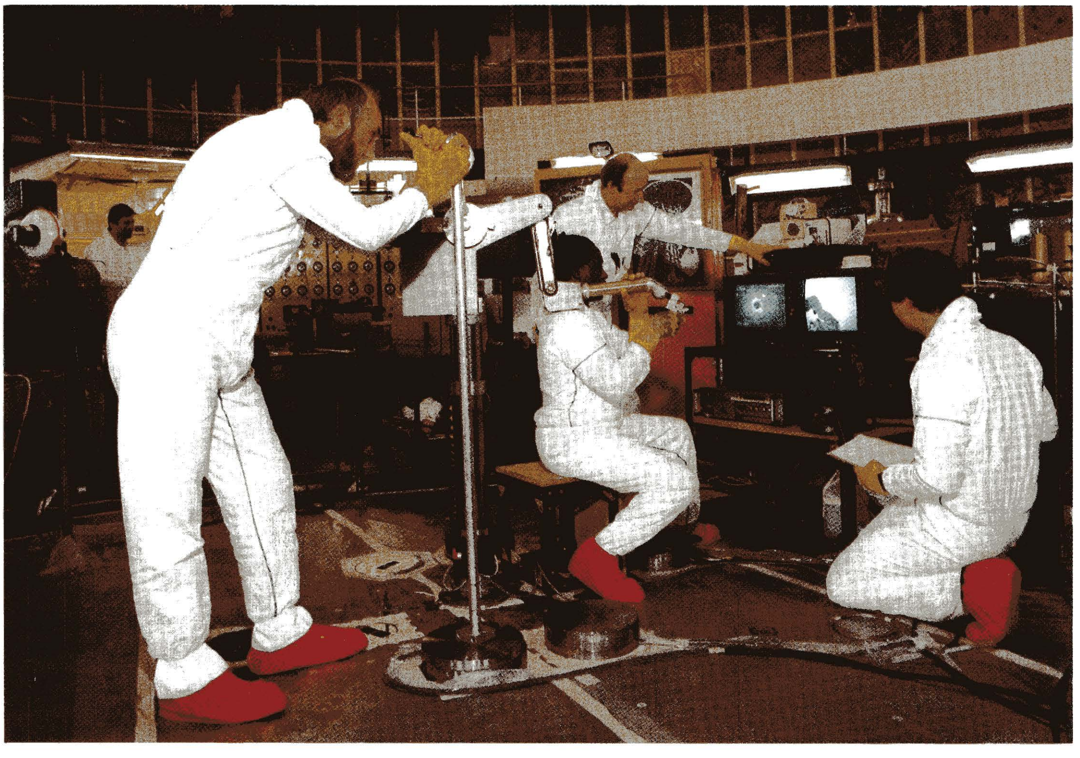
These protection principles are enforced through systems of control, established by the appropriate authorities, which generally involve notification, registration and licensing of any sources or practices that involve radiation exposures of people.

In addition to the principles and control systems relating directly to radiation protection, radioactive waste management is also subject to a number of more general principles, involving ethical and sociological questions, the protection of the environment and natural resources, and safeguards to limit the spread of nuclear weapons.

COMMUNITY REGULATIONS

The principles, standards and requirements relating to nuclear and environmental matters in all Member States of the European Community are based on the Treaty of the European Atomic Energy Community (Euratom) of 1957, the Treaty of the European Economic Community (EEC) of 1957 and the Single European Act of 1987. They are implemented in accordance with the requirements of these treaties, through formal and binding regulations, directives and decisions.

The Commission is assisted in these tasks by appropriate advisory groups of experts, in particular in the field of radioactive waste by the Advisory Committee on the Implementation of



Agencies responsible for treatment and conditioning, transport, storage and disposal of radioactive waste in the EC.

COUNTRY	AGENCY	RESPONSIBILITIES			
Countries with nuclear power stations		Treatment and conditioning	Transport	Storage	Disposal
BELGIUM	ONDRAF/NIRAS	In parallel with waste producers	ONDRAF/NIRAS	ONDRAF/NIRAS	ONDRAF/NIRAS
GERMANY	BfS	Waste producers	Performed by industry after permit from BfS	By industry and/or federal centres	
FRANCE	ANDRA	Waste producers	ANDRA (partially)	By industry	ANDRA
SPAIN	ENRESA	ENRESA (in particular cases and circumstances)	ENRESA	ENRESA	ENRESA
ITALY	NUCLECO	Waste producers	Commercial operators	NUCLECO	No decision on disposal taken
THE NETHERLANDS	COVRA	COVRA (for low and medium level waste)	COVRA (for low and medium level waste)	COVRA	Decision for disposal route delayed to next century
UNITED KINGDOM	UK NIREX Ltd	Waste producers	Waste producers	Waste producers (nuclear industry)	UK NIREX Ltd (for low, medium and alpha wastes)
Countries without nuclear power stations					
DENMARK		The Risø national laboratory, by agreement with the National Health Service, is responsible for collecting and storing radioactive waste from hospitals and industries.			
GREECE		Management and storage are the task of the ministries concerned in cooperation with the Atomic Energy Commission and the Demokritos Research Centre.			
IRELAND		The Nuclear Energy Board is responsible for the regulation of the storage and disposal of radioactive waste from industry, research laboratories and hospitals.			
PORTUGAL		The collection, packaging and storage of radioactive waste from industry, research laboratories and hospitals are carried out by the Department of Radiological Protection and Safety of the Laboratório Nacional de Engenheria e Tecnologia Industrial.			

the Community Plan of Action on Radioactive Waste Management.

NATIONAL CONTROL

International guidance and EC principles, standards and requirements constitute sets of recommended measures, legally binding in the case of the EC measures, that are sufficiently general to be incorporated into the national legal frameworks of Member States. The precise national control measures used depend on the particular economic, socio-political, legal and institutional structures and geographic conditions of each country, making attempts at harmonisation difficult. All must, however, comply with the appropriate EC health and safety requirements.

In practice, there are many common features between the ways wastes are dealt with in different countries. Commonly, the main parties involved are:

- the waste producers;
- the waste operators: executive bodies responsible for all or part of waste management;
- the regulatory authorities;
- the government.

The waste producers are the originators of the wastes, and have to be registered as such by the regulatory authorities in each country. They are generally responsible for the wastes up to delivery at the disposal site, but in some cases, particularly producers of small quantities, responsibility may be passed to other competent bodies.

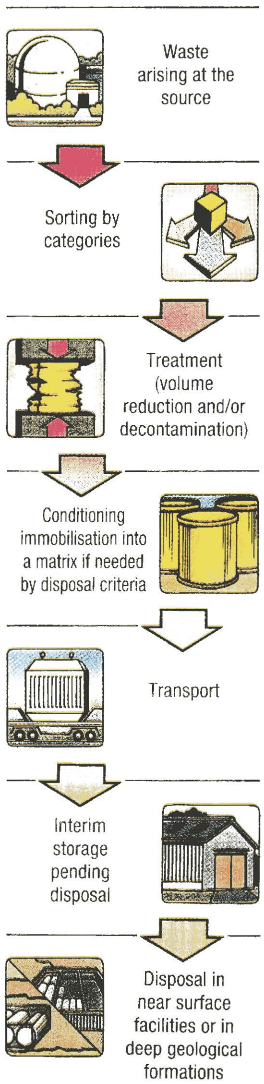
The waste operators are responsible for disposal and, to a variable extent, management. They accept the waste packages delivered to them by the waste producers for interim storage and disposal if the packages meet the appropriate acceptance criteria. The responsibilities of the waste operators in the Member States for different aspects of waste management are set out in the table.

The regulatory authorities are responsible for the development of the regulatory framework, the control of its implementation and for the licensing of facilities, including those for waste management and disposal.

The governments are responsible for national radioactive waste management policies and are ultimately responsible for the long term safety of disposal.

WASTE MANAGEMENT IN PRACTICE

Typical radioactive waste management scheme.



Protection of people from unacceptable exposures to radiation – the fundamental objective of radioactive waste management – can best be achieved by the use of one or more containment barriers to surround and isolate the wastes. The barriers fulfil two roles: they shield people from the radiation emitted by the wastes, and they prevent or retard their movement, ensuring that they do not reach people in unacceptable concentrations. The barriers can be man-made or natural.

The design of facilities for treating, conditioning, transporting, storing and disposing of wastes is dominated by two main properties of the wastes:

- the radiation levels, which govern the amount of shielding needed to protect people from direct radiation;
- the lifetimes, which govern the time for which the wastes have to be isolated from people.

The provision of adequate shielding is relatively straightforward. Even the most intense radiation can be stopped by a sufficient thickness of concrete, while some types will not even penetrate a thin sheet of plastic or metal. Water is a particularly effective form of shielding and the most highly radioactive materials, such as used nuclear fuel, are generally stored under water for several months, till the most intense radiation has died away.

The main requirement is then to ensure that the wastes remain isolated from people for the necessary length of time. This will vary, depending on the type of waste.

This chapter describes the various stages of radioactive waste management, showing how the necessary containment barriers can be provided.

THE MANAGEMENT SYSTEM

A typical sequence of waste management operations is: collection, sorting, treatment, conditioning, transport, storage and, finally, disposal. These activities are closely linked through numerous interactions and need to be planned as a whole in order to maximise safety and minimise costs. For example, in the absence of a decision on an ultimate disposal route, a form of packaging may be selected which is only adequate for the purpose of interim storage. Repackaging may then be needed before final disposal, with the possibility of additional worker exposures.

An integrated "systems approach" is now being developed worldwide that identifies the many interactions between the components of the overall management system. This approach is being taken into account in the waste management policies of the Member States.

TREATMENT AND CONDITIONING

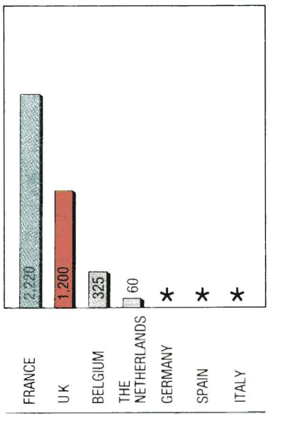
After collection and sorting into appropriate categories, wastes generally have to be treated and conditioned in order to put them into a form suitable for safe handling, storage and disposal.

Treatment methods include compaction and incineration of solid wastes and evaporation and chemical precipitation of liquid wastes.

Conditioning generally consists of incorporating the treated wastes in matrices which solidify into blocks, usually within external containers, which provide the necessary safety features such as good mechanical strength, resistance to fire, low

WASTE OF ALL CATEGORIES IN INTERIM STORAGE

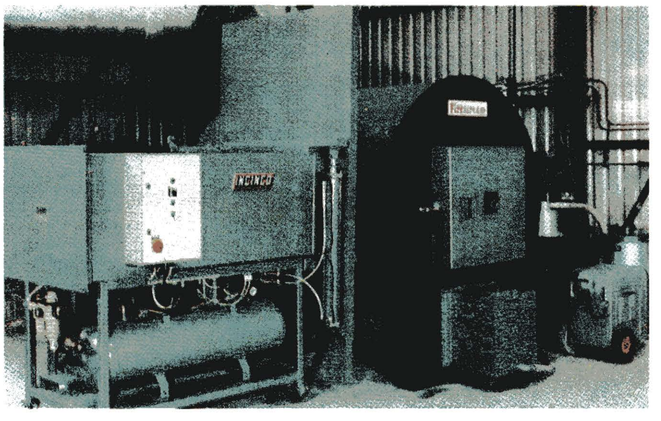
1. Drums of low level waste are compressed in super-compactors to enable more efficient use of space to be made in repositories.



Interim storage of vitrified high level waste within the European Community, current and planned capacity (m^3).

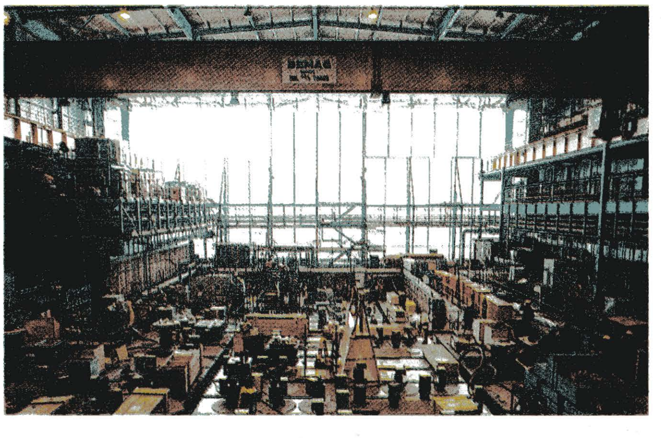
*Planned.

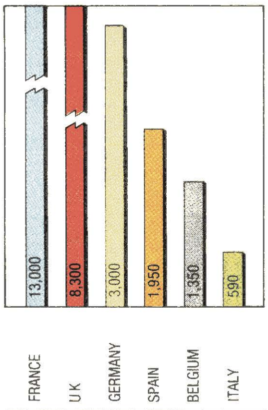
2. Some categories of waste can be safely incinerated, leaving small quantities of ash for disposal. Gases are filtered before being released to the atmosphere.



3. Ion exchange plant is used to extract radioactive caesium and strontium from liquid effluents. Then the extracted material is immobilised in concrete for disposal deep underground.

4. Plant at Sellafield, UK, for the removal of alpha emitters. The extracted long-lived alpha wastes will be buried deep underground.





Storage capacities for spent fuel (tons of heavy metal) within the European Community, 1990.

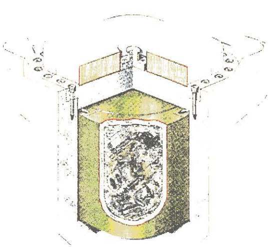
solubility and good long term behaviour. The most common matrices are cements, bitumens and polymers.

TRANSPORT

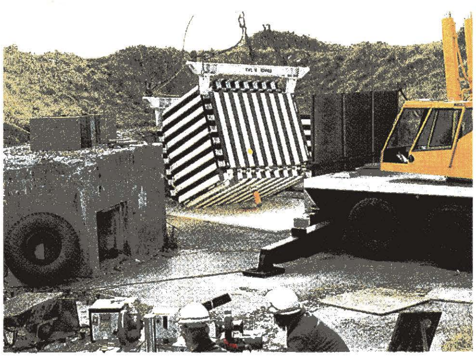
The transport of radioactive materials has for many years been governed by the provisions of the IAEA, which form the basis for national regulations in EC Member States. The IAEA regulations are designed to ensure that the materials are adequately contained, that adequate shielding is provided, and that any heat generated, for example by high level wastes, is safely dissipated. In addition, when transporting fissile material (material in which a nuclear chain reaction can be sustained) the designs used must ensure that a critical chain reaction (one that is self-sustaining) will not occur.

The IAEA approach to safety is to ensure that the packaging itself will provide the necessary degree of protection, irrespective of the vehicle carrying it, the transport route, and transport conditions, including accidents. The requirements include stringent test procedures, independent assessments, certification of compliance by the competent authority and the availability of emergency response measures should an accident occur.

The main movements of radioactive waste packages are from the producers to centralised storage or disposal facilities. Most radioactive wastes are transported in solid form, but in some countries specially designed and shielded containers are used for liquid wastes. The record of radioactive waste transport in EC Member States has been excellent, giving confidence both in the technology and in the regulatory framework. Transfrontier transport is subject to a recent EC Directive requiring prior notification of shipments and to IAEA regulations and codes of practice. The EC Directive has to be incorporated into national legislation before January 1994.

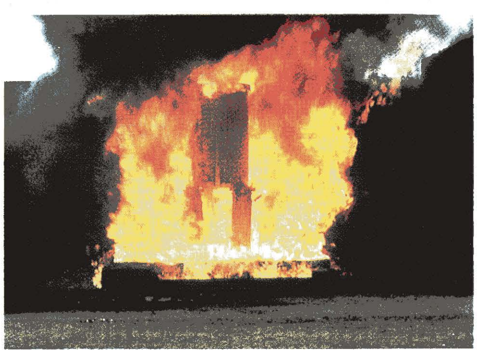


Design for a transport container for medium level waste.



1. Transport containers are tested by dropping them onto concrete platforms or steel spikes from up to 9 metres.

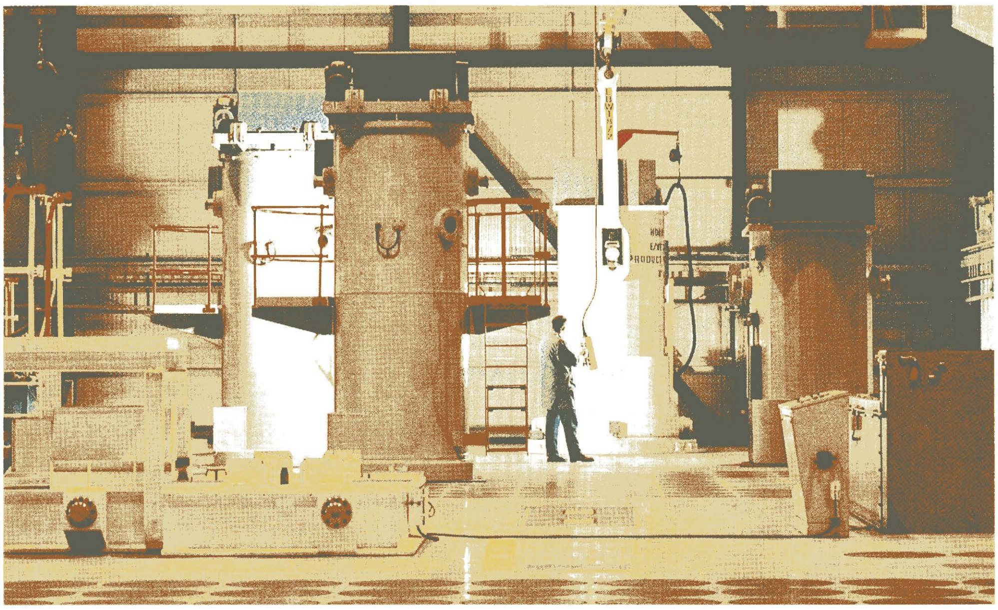
2. A transport container for used nuclear fuel survived intact a test collision with a diesel locomotive travelling at 160 kilometres an hour.



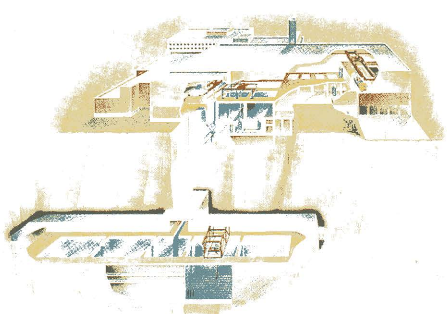
3. Transport containers are designed to resist many hours of exposure to high temperatures. Standard test requirements are up to a half hour at 800°C, but some containers are tested under even more severe conditions.

INTERIM STORAGE

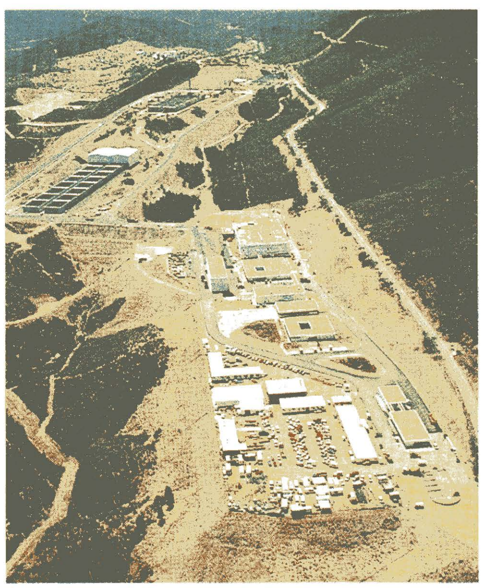
The key and final step in radioactive waste management is disposal. In many cases, however, interim storage may be needed, for example to allow heat generation to die away, to enable optimum management strategies to be developed, and to allow disposal sites to be identified and studied in sufficient detail to enable their long term safety to be established. In particular, continuing public unease concerning the nuclear industry in general has led to the development of strong local opposition to the development of new waste disposal facilities, which has in turn led to an increased need for interim storage, either on the sites of production or in centralised storage facilities. One valuable side effect of this situation has been to encourage the development of very effective volume reduction techniques, such as supercompaction and incineration, to save room for storage.



Vitrified high level waste, encased in stainless steel, is stored in air-cooled vaults, typically for 30 to 50 years, before disposal deep underground.



The CLAB facility near the Oskarshamn nuclear power station in Sweden will store used nuclear fuel for around 40 years before encapsulation and disposal deep underground.



At El Cabril, in Spain, waste suitable for near surface disposal will be placed in concrete structures similar to those developed in other countries.

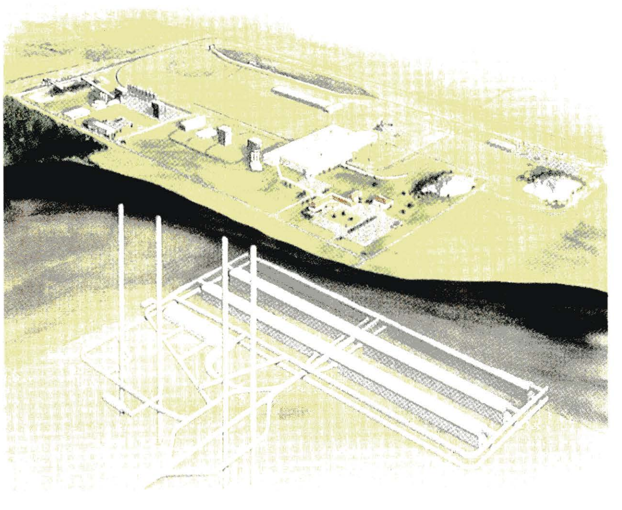
DISPOSAL

Radioactive wastes can, in principle, be stored indefinitely, given continuing surveillance and maintenance of the storage facilities, including periodic rebuilding when needed. However, a fundamental principle of waste management is the avoidance of any undue burden on future generations. There is a broad international consensus that the best way of achieving this objective is to dispose of wastes, using a combination of man-made and natural barriers, in a way that requires no further action to ensure safety.

There are two main approaches to such final disposal: sea disposal, and land disposal by burial either in near surface or in deep underground repositories.

Sea disposal was used for some categories of wastes by a number of countries up to 1983, when a voluntary moratorium was agreed, which is still in force pending the completion of various studies which are expected to be finished in 1993. Recently, the parties to the Convention for the Prevention of Marine Pollution from Land-Based Sources (known as the Paris Convention), have decided a moratorium of 15 years for sea dumping of radioactive waste in the North Atlantic. A total of nearly 60,000 cubic metres of low and medium level waste were disposed of at sea by EC countries up to 1983.

A total of about 1.3 million cubic metres of low and medium level waste were disposed of in EC countries on land, in near surface and in deep repositories, up to the end of 1990. Near surface disposals have been carried out in Germany, France and the United Kingdom, and deep disposals in Germany. No disposals of alpha or high level wastes have yet taken place.



A deep underground repository concept being developed by UK Nirex Ltd at the Sellafield site.

Low level waste in steel drums can be safely handled using minimal protection such as overalls and rubber gloves.

SAFETY ASSESSMENT

Safety in the nuclear industry can often be demonstrated by a series of practical tests. For example, the safety of transport containers for radioactive materials has been demonstrated by crash tests, drop tests and fire tests; the inherent safety characteristics of a sodium cooled fast reactor have been demonstrated by switching off the pumps that circulate the coolant and showing that it does not overheat as a result. Such tests, though extreme, are similar in principle to safety tests carried out on a whole range of engineering structures and on consumer products such as cars and domestic appliances. Absolute safety cannot be guaranteed in any human activity, but virtually any safety standard can generally be met by careful design and testing, and by learning from the past.

When an activity spans time scales beyond one or two human generations, however, past experience and performance testing are of limited use. A prime example of this is the disposal of long lived radioactive waste, or of some chemical wastes that retain their toxicity for ever. Other examples are the use of chemicals or pharmaceuticals that can have harmful effects many years or even generations after their introduction, and the emission of some pollutants and greenhouse gases that can have long term effects on the environment or the climate. The consequences of such activities can only be assessed by a combination of experiments that can be carried out in a reasonably short time, typically months or years, and predictions of what is likely to happen in the future, based on a detailed understanding of all the processes involved. These can sometimes be complemented by studies of natural analogues which have spanned relevant time scales. Such approaches are the essence of the safety assessments that are being carried out in support of the radioactive waste disposal programmes in the Community and elsewhere.

The work falls into two parts: assessment and research. The objective of an assessment is generally to demonstrate that a specific disposal operation at a given site will satisfy the safety requirements under all conceivable future circumstances. The objective of the research programme is to provide the necessary understanding and data on the wide range of physical, chemical, biological and geological processes of relevance to the safety case, and to develop the mathematical models of the ways these processes operate and interact. This information is then used in the assessment process. Safety assessments are described in this chapter, the research programmes in the next.

SAFETY OF PREDISPOSAL ACTIVITIES

Facilities and plants for the treatment and conditioning, transport and storage of radioactive waste are subject to the same safety requirements as any other nuclear plants. Safety assessment of these stages of radioactive waste management does not present any new or particularly difficult problems.

In common with all nuclear activities, safety is constantly under review and is improved wherever practicable in the light of developments in technology, as required by the ALARA principle. Examples of such improvements include the reduction of radioactive releases to the environment from the reprocessing plants at la Hague and Sellafield, the development of technologies and processes for the characterisation, quality control, identification and tracking of waste packages, and continuing reductions in occupational exposures from all waste management operations.

SAFETY OF NEAR SURFACE DISPOSALS

Short lived wastes, which lose almost all of their radioactivity within a few hundred years, can be safely disposed of in near surface facilities provided that a suitable degree of isolation is provided for the necessary period. In the early days of nuclear energy, some countries carried out such disposals in shallow trenches without any special conditioning or packaging of the wastes. Assessments of the safety of such disposals, by bodies such as the National Radiological Protection Board in the UK, found that negligible radiation exposures would result, and this has been confirmed by detailed environmental monitoring. This early concept is, however, now considered obsolete and more advanced concepts have been developed and implemented. These generally make use of several barriers: the material in which the waste is embedded, if any, the waste package, the engineered structures of the repository and the geology of the site itself.

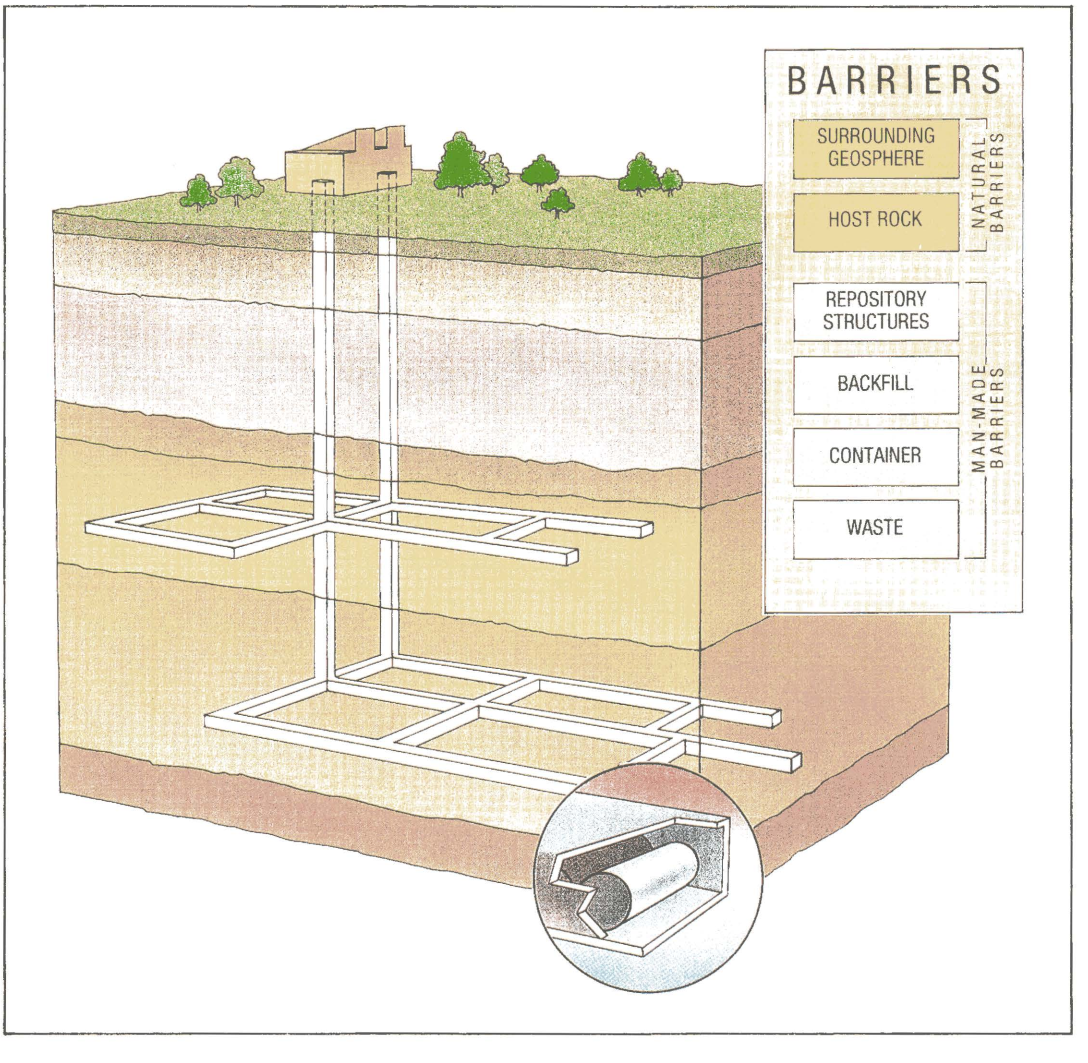
Assessments of the safety of such repositories have been carried out in a number of countries. The assessments cover the operational phase, usually lasting several decades, and the post-closure period, generally a maximum of a few hundred years, during which some measure of institutional control, such as limitation of access, may be needed. Such assessments have shown that the consequences of any foreseeable incident are acceptably low, and several national safety authorities have accordingly given their approval for the construction and operation of engineered near surface repositories for low and medium level wastes.

SAFETY OF DEEP DISPOSALS

The safety of long lived wastes cannot be ensured by the provision of engineered structures alone, and the approach being pursued in all countries which have to dispose of such wastes is to build deep underground repositories in geological environments that have retained their isolation capabilities for millions of years (like salt formations) or that are very efficient at retarding the movement of radionuclides back to the biosphere. Uranium-rich deposits are natural examples of such environments.

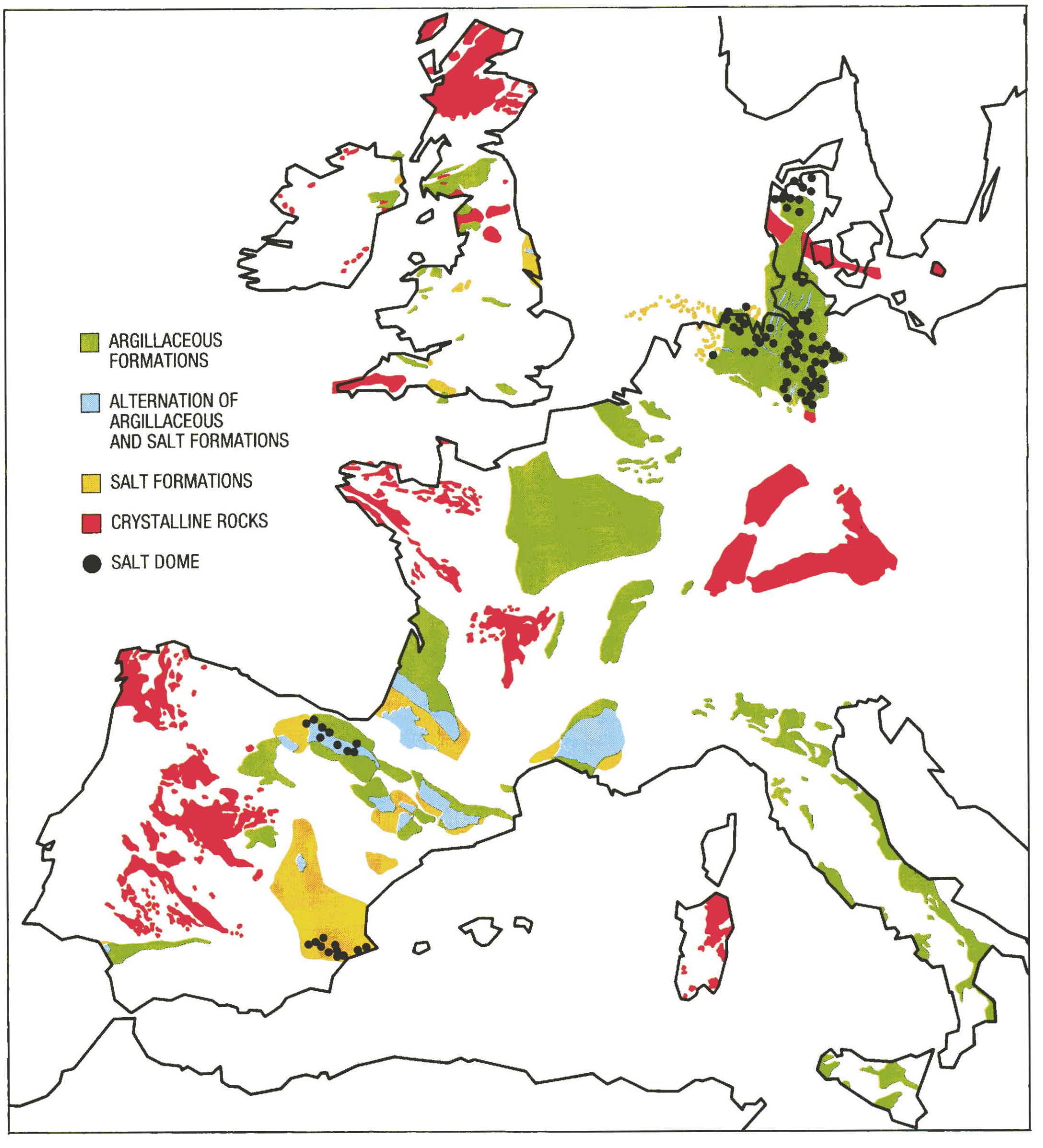
Assessment of the safety of a deep geological repository consists essentially of a detailed analysis of the possible long term consequences of the disposal in order to quantify any potential risk that may arise at any time following the final closure of the repository. The results then have to be compared with the appropriate safety standards. The assessment process also helps to identify key areas where additional research may be needed and provides guidance for site selection and repository design.

The necessary degree of isolation of the wastes is provided by three groups of barriers: the engineered barriers immediately surrounding the wastes (the waste form itself, the container, backfilling material and the underground structures); the geosphere (the geological formations between the repository and the biosphere); and the biosphere (soil, lakes, rivers and seas, the atmosphere, and plant and animal life). Radioactive materials have to be transported through all three groups of barriers before reaching people, and the assessment considers all possible ways in which radioactive materials can move through the barriers. A range of futures has to be considered, taking into account possible human activities such as mining operations, and possible long term climatic, geological or hydrological changes.



The multi-barrier concept for deep disposals.

PAGIS: geological formations having suitable characteristics for deep underground repositories (the former East Germany, Portugal and Greece not included).



There has been very considerable progress in understanding all the relevant processes and in carrying out safety assessments over the past few years, in national and international programmes. In particular, within the European Community, the CEC launched in 1982 a large multinational project (PAGIS: Performance Assessment of Geological Isolation Systems). The methodology developed within this project has been applied to the case of deep repositories for high level waste at a number of defined sites. The results of the assessments under this project have been highly reassuring, showing no radioactivity release at any of the sites investigated within 10,000 years at least and radiologically insignificant releases in the very distant future. The PAGIS methodology can be, and already is in some Member States, the basis for performance assessments using refined models and data from site specific investigations.

These achievements, together with those outside the EC, led the international scientific community to express a collective opinion in 1990, which says:

"Safety assessment methods are available today to evaluate adequately the potential long term radiological impacts of a carefully designed radioactive waste disposal system on humans and the environment; appropriate use of safety assessment methods, coupled with sufficient information from proposed disposal sites, can provide the technical basis to decide whether specific disposal systems would offer society a satisfactory level of safety for both current and future generations."

Work is continuing to further develop safety assessment methods and to evaluate data from proposed disposal sites.

RESEARCH AND DEVELOPMENT

Important research and development programmes on radioactive waste management and disposal have been carried out at national and Community levels for many years. The resulting knowledge, which is considerable and has been widely disseminated, gives no ground for doubting that waste of all types could be managed and disposed of safely on an industrial scale.

Programmes are therefore increasingly being directed towards the optimisation of waste management, particularly the minimisation of volumes to be disposed of, reduction of discharges to the environment well below existing discharge limits, and the development of the deep underground repositories and assessments of their safety.

Expenditure on research and development activities has in general been maintained or even increased during the past three years, both at national and at Commission levels. There is exceptionally strong and effective international cooperation, and the Commission is very active in promoting such cooperation through its R&D programme and the EC Plan of Action in the field of radioactive waste. Lists of publications resulting from the Commission's cost-sharing programmes are published in the EUR series of reports.

This chapter gives some examples, taken from the very wide range of activities, of research in conventional laboratories, investigations in underground laboratories and pilot facilities, and studies of natural analogues.

LABORATORY STUDIES

The main object of the experimental and theoretical studies that are being carried out in research laboratories all over the world is to provide data and understanding of the physical, chemical and microbiological processes that govern the movement of radioactive materials in the repository itself, in the geological formations between the repository and the surface (the geosphere), and in the biosphere. The programmes also examine the validity of the key assumptions used in the safety assessment process and provide the mathematical models used for the assessments.

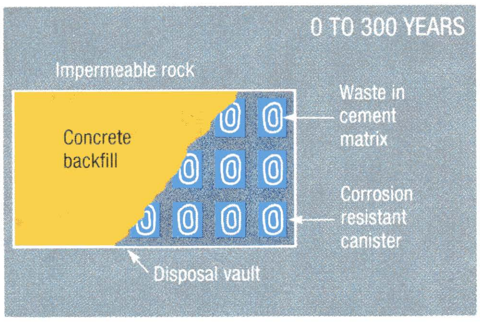
The research programmes reflect the multi-barrier approach, in which processes within and in the immediate surroundings of the repository, in the geosphere and in the biosphere, all contribute to meeting the safety criteria.

The programmes, which provide information on the long term behaviour of the repository itself, include studies of the physical performance of steels and concrete, of the influence of chemical conditions within the repository on the solubility and sorption of radioactive materials, and of the generation and movement of gases within the repository.

Geosphere research includes studies of the flows of water and gas through various types of rock, using both uniform and fractured rock samples, and of the movement of radioactive material through rocks, which can be thousands of times slower than the movement of water because of sorption processes.

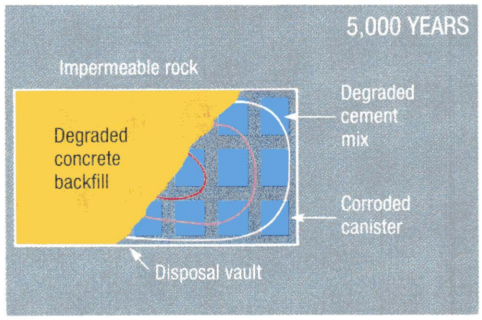
The vast majority of any radioactive material which has been carried away from the repository by flowing groundwater will have decayed to a harmless non-radioactive state by the time it approaches the surface. The biosphere research programmes investigate the ways any small traces of radioactive material which may remain move within the biosphere. The processes and the rates at which they occur are already well known as a result of extensive research in the context of discharges of radioactive effluents from nuclear installations, fallout from atmospheric nuclear

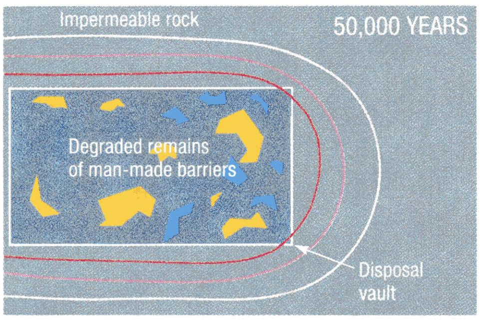
Mathematical models are used to predict the likely movement of radioactive materials out of a typical deep underground repository and through the surrounding geological formations.



0 to 300 years
The engineered structures of the repository are designed to stay intact for several centuries.

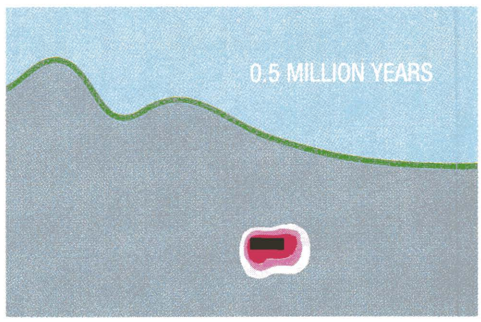
5,000 years
Groundwater will gradually penetrate the repositories and cause corrosion and degradation of the engineered structures. At this time, the radioactivity of the wastes will have fallen to a small fraction of its initial value.

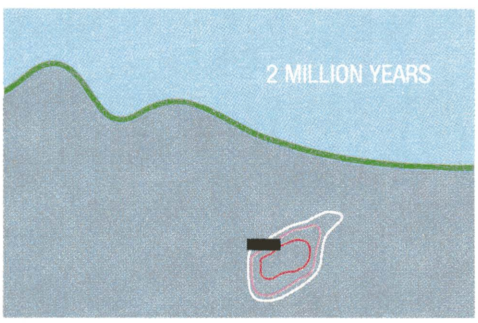




50,000 years
After tens of thousands of years, some radioactive materials will begin to move into the surrounding rocks.

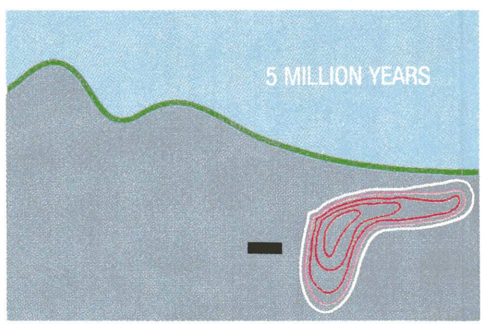
0.5 million years
After hundreds of thousands of years, groundwater will be carrying traces of radioactive material through the surrounding strata. Sorption processes will ensure that radioactive material moves around more slowly from the groundwater itself.





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

5 million years
Even if extremely small quantities of radioactive material eventually reach the surface, they will be further diluted as they move through the biosphere and contribute radiologically insignificant doses.



weapons tests and movements of natural radioactivity, principally radon gas. The research therefore concentrates on specific ways in which radioactive materials from a deep underground repository may enter the biosphere from below.

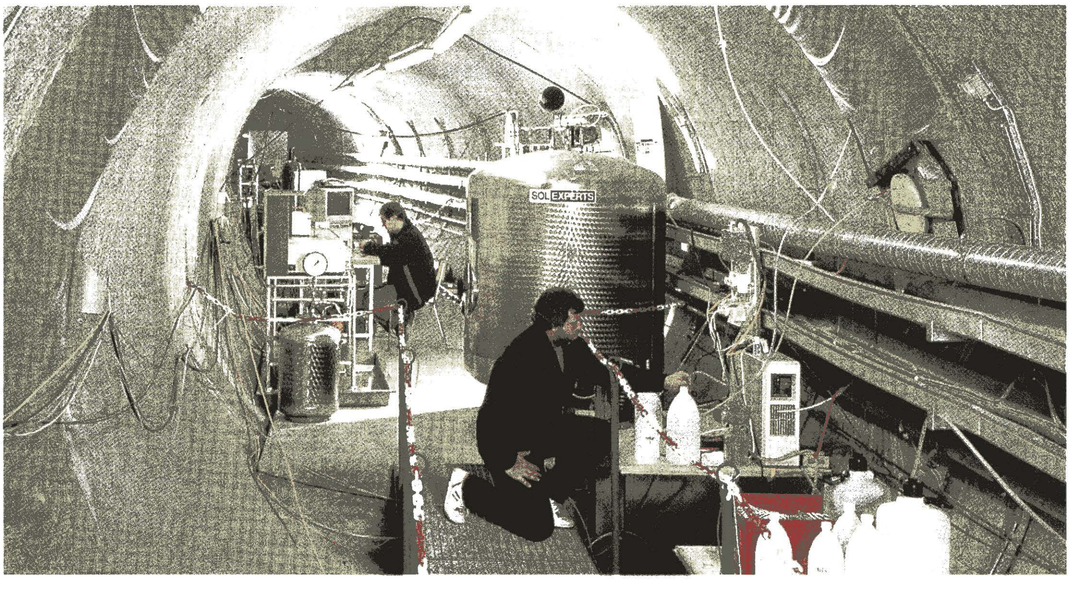
An additional area of research, not directly related to the disposal of wastes, is the transmutation of long lived radioactive species into short lived ones. This can be done in nuclear reactors; indeed the very process of power generation in nuclear reactors involves the transmutation of long lived uranium fuel into generally short lived radioactive waste, which also happens to contain some long lived material. A strategy of transmuting long lived wastes would require special "burners" (eg fast reactors) and reprocessing facilities, which would be costly and would inevitably involve some additional radiation exposures. However, the possibility of reducing the amount of long lived material in the wastes might increase the safety of geological disposal and is therefore being investigated in the EC and elsewhere. The effort in terms of budget is currently very limited; EC country involvement mainly concerns France and to a lesser extent the Netherlands and Germany.

UNDERGROUND LABORATORIES AND PILOT FACILITIES

Research in underground laboratories and pilot facilities is used to extend, supplement and confirm work done elsewhere, to develop rock characterisation methods and instrumentation, to provide in situ geological and other information on potential host rocks or rock types in support of safety assessment programmes, to validate the models used in the assessments, and to evaluate the engineering feasibility of repository construction, operation and closure.

Facilities where such studies have been or are currently being carried out exist in Belgium, Canada, Finland, France, Germany, Italy, Japan, Sweden, Switzerland and the USA. Many of these sites are used for internationally coordinated programmes.

Rock formation	Laboratory
Salt	Salt Vault (Kansas), USA Avery Island (Louisiana), USA WIPP (New Mexico), USA Asse (Niedersachsen), Germany Amélie (Alsace), France
Crystalline rock	Stripa, Sweden Grimsel, Switzerland Edgar Mine (Colorado), USA Troon (Cornwall), UK URL (Manitoba), Canada Climax Mine (Nevada), USA Fanay Augeres, France Akenobe Mine, Japan Hard Rock Laboratory, Sweden NSTF (Washington), USA G-Tunnel (Nevada), USA
Argillaceous rock	Mol, Belgium Pasquasia, Italy Tournemire, France



NATURAL ANALOGUES

There are many examples in nature of radioactive materials that have been effectively isolated for extremely long periods and that can be used to demonstrate the basic feasibility of geological containment of radioactive wastes. One of the most important of these is the series of natural nuclear reactors that occurred spontaneously in very rich uranium ores at Oklo in Gabon, starting about 2,000 million years ago. The way in which the radioactive wastes that were produced in these reactors subsequently moved matched closely the predictions made in safety assessments of model repositories. Another example is the very rich, 1,300 million year old uranium deposit near Cigar Lake in Canada. The continuing existence of this deposit demonstrates the remarkable retentive properties of the layer of clay 5 to 30 metres thick that surrounds it.

Oklo, site of the oldest known nuclear reactor, has provided valuable information on the very long term isolation of radioactive wastes.

FINANCIAL AND SOCIAL ISSUES

The previous chapters have summarised the technical approaches being applied to radioactive waste management in EC Member States and elsewhere. A fundamental requirement to be satisfied, however, before the various stages of waste management are implemented, is to ensure that any resulting radiation exposures are justified by the benefits that arise from the nuclear electricity production or from the other activities that give rise to wastes. It is also essential that the financial costs of the operations are not so great as to negate these benefits. In other words, optimisation of radiation exposures and costs must be achieved at all stages of waste management and disposal. Implementation also depends on achieving a measure of public acceptance which can only result from a sufficient level of public understanding of the issues. These questions are addressed in this final chapter.

COSTS

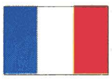
The "Polluter Should Pay" principle has formed the basis for financing waste management and disposal by EC Member States for many years. It has been incorporated into the laws of several countries (Belgium, France, Germany, Italy, Spain) and the bodies responsible for managing the wastes are financed, at least in part, through payments by the waste producers.

Waste management costs, particularly disposal costs, are commonly perceived as being very high. Indeed in the case of nuclear power in some countries, they are sometimes believed to affect its future economic competitiveness. This misconception probably arises from the high absolute costs of the operations. For example a figure of around £3.2 billion (about 4.5 billion ECU) has been suggested as the probable cost, over the 50 year operating period, of Nirex's proposed deep disposal facility in the UK. Such costs must, however, be seen in the context of the value of the electricity production that gives rise to the waste; in the case of the Nirex repository this is of the order of several hundred billion pounds. In general, waste management costs are of the order of a few per cent, at most, of the total cost of generating electricity from nuclear power.

The costs of management and disposal are commonly expressed in terms of the cost per cubic metre of waste. This depends on a number of factors such as the type of waste, the precise management route specified by the various national strategies, the timing of the operations, for example the duration of the pre-disposal storage period, and the design, geological conditions and overall size of the repository. In many cases, precise designs have not yet been developed and only approximate cost estimates are available. These are summarised in a recent EC report EUR 12871 EN (1990). The main conclusions of this report are:

- the costs of pre-disposal storage are likely to range from 400 to 1,300 ECU per cubic metre for low level waste, 10,000 to 20,000 ECU per cubic metre for medium level and non-vitrified high level waste and of the order of 100,000 ECU per cubic metre for vitrified high level waste;
- the costs of disposal are likely to range from 1,000 to 3,000 ECU per cubic metre for surface or near surface disposal of low level waste, 2,000 to 6,000 ECU per cubic metre for deep disposal of low level waste, 10,000 to 70,000 ECU per cubic metre for deep disposal of medium level waste and 0.4 to 1.4 million ECU per cubic metre for deep disposal of vitrified high level waste. The relatively large range of figures results mainly from the fact that the costs are dominated by the costs of site selection and construction and not very sensitive to the amount of waste to be disposed of. Thus the total cost per cubic metre is higher in a country that only has to deal with a small quantity of waste.

Financial provisions for waste management activities in the Member States of the European Community.

Country	Extent and coverage of provisions	Basis for gathering provisions	Particular arrangements
BELGIUM 	ONDRAF activities recovered in full from waste producers; long term activity expenses covered by special fund to be set up from producer contribution	Projected cost of operation	Producer liability for costs due to lack of conformity of product over 50 years
GERMANY 	BfS levies advance contributions from waste producers to cover total expenditure	Amount decided by annual estimate of expenditure	Advance payments are shared among waste producers according to their category
FRANCE 	ANDRA funding comes from waste producers on an effective cost basis; pre-funding for future expenses is charged to producers	Effective running cost calculated according to volume and nature of delivered wastes; pre-funding based on future delivery forecasts	Capital investments partly financed by loans with interest paid by waste producer
ITALY 	NUCLECO services are paid for by waste producers; ENEA budget is included in the budget of the Ministry of Industry, Commerce and Crafts	Effective costs (spent fuel management costs are collected as estimated costs proportional to amount of of electricity produced)	
THE NETHERLANDS 	All costs of COVRA activities are covered by fees paid for waste transferred to COVRA; included is an amount to cover costs of final disposal after interim storage; ECN is financed by income from services supplied and by government grants	Estimated cost depending on waste type	
SPAIN 	ENRESA charges direct cost of services to waste producers; fees to cover total waste management collected from electricity producers; CSN obtains funds from inspection and other services and from the state budget	Direct costs of services and proportional fee on electricity revenue estimated annually	
UNITED KINGDOM 	Operating costs of Nirex are borne by shareholders from revenue	Effectively occurring operation costs	Allocation of costs for repository construction not yet known
	CEGB makes provisions for long term liabilities	Estimated cost	
	BNFL makes provisions for expected costs of storage of HLW and MLW (**not** for cost of final disposal); for wastes with disposal route available (LLW) total costs are covered	Estimated costs for HLW and MLW storage and total costs for LLW	Costs for LLW disposal are written off in the year in which they occur
	For UKAEA waste the Secretary of State for Energy carries costs from programmes before April 1986	None	Costs are covered as they arise

The report stresses that the figures are provisional and to be used essentially to assess the comparative costs of different management strategies; more accurate figures will become available as disposal projects evolve.

In addition to the low, medium and high level waste categories, there are a wide range of wastes containing very low levels of radioactivity, similar to those of many naturally occurring substances. Examples include waste from medical analysis and treatment, research institute waste, discarded consumer products like smoke detectors, and waste from the luminous paint and the phosphate industry. Of similar radioactivity are many wastes from the nuclear industry, particularly the large quantities of scrap that result from the dismantling of obsolete installations. It is important that appropriate regulatory measures are applied to the management of these wastes so that unreasonable costs are not incurred simply because of the high level of public concern about radioactive wastes in general. There is scope for the development of more coherent and scientifically sound rules for the management of these types of waste and for their harmonisation internationally and within the EC; such developments are now in hand.

PUBLIC INFORMATION AND INVOLVEMENT

It is important that everyone in the European Community is well informed on matters that may affect their environment or their health and that the public is involved in the decision making processes. An EC Directive which entered into force in 1988 asks Member States to take care that:

- every licensing request for a new project and the supporting information will be made available to the public;
- the public has the opportunity to make known its opinion before the project is begun.

The organisations involved in waste management and the Commission have, during the past few years, made great efforts to inform the public about major nuclear sites and their radioactive discharges and to involve them in the decision making processes relating to new installations for radioactive waste management and disposal.

In many cases the public is given access to any applications to set up such facilities and, in the case of major projects, there is often a public inquiry which:

- gives the public information on the project under consideration;
- collects the comments and objections of the public for consideration by the appropriate national body.

In most cases, the public inquiry process is legally based; it may be compulsory (France, Germany, the Netherlands, Spain) or, as in the United Kingdom, for the government to consider its use on a case by case basis.

In addition to information made available to the public by means of booklets, information centres, visits to nuclear installations, etc. or by giving access to official documents, several governments report at various intervals to the national parliaments about matters relating to radioactive wastes and these reports are publicly available.

Those responsible for the safe management and disposal of radioactive wastes and the bodies involved in its regulation are thus firmly committed to maximising the extent of public information and involvement in their activities. It is hoped that this booklet will contribute to this process.

INFORMATION/SOURCE TABLES

TABLE I
Radioactive waste arising from use of isotopes in medicine, industry and general research (m^3).
(Liquid and solid waste shipped for centralised interim storage.)

(1) Extrapolated from figures given for period up to 2000.
(2) Unconditioned and held at site of production.
(3) Waste volumes before treatment and conditioning.
(4) Per five-year period.
(5) Periods: 1990-1994, 1995-1999, 2000-2009, 2010-2019.

Country	1991-1995	1996-2000	2001-2010	2011-2020
BELGIUM	370	370	740	740
DENMARK	100	100	200	100
GERMANY	5,100	5,100	10,200 (1)	10,200 (1)
IRELAND	some tens (2)	some tens (2)		
SPAIN	210	210	420	420
FRANCE (3)	5,000	5,000	10,000	10,000
GREECE	100	some tens	some tens (4)	some tens (4)
ITALY	4,500	4,500	9,000	9,000
THE NETHERLANDS	1,600	1,600	3,200	3,200
PORTUGAL	20	30	80	100
UNITED KINGDOM (5)	4,960	3,030	5,610	5,610

TABLE 2
Waste in interim storage produced before 1991, treated and conditioned or presumed to have been conditioned (1).

(1) Most of the alpha and HLW (stored in liquid form) has not yet been conditioned. For uniformity of presentation, the volumes in this table are those which could be obtained by conditioning the waste with the methods available at present.
(2) Partially included in LLW (as waste "without heat generation") and in HLW (as "heat generation waste").
(3) The unconditioned quantities in interim storage are: 12,195 m^3 LLW (11,620 m^3 solid and 575 m^3 liquid); 585 m^3 solid MLW; 356 m^3 alpha (346 m^3 solid and 10 m^3 liquid); 120 m^3 liquid HLW.
The conditioned quantities in interim storage are: 3,610 m^3 LLW and 345 m^3 MLW.
A volume reduction factor between 3 and 5 for solid waste to be compacted, and a reduction factor of ½ for liquid LLW is assumed.
Figures do not include about 5,000-7,000 m^3 of unconditioned waste coming from medical, industrial and non-nuclear research.
(4) Only half of the volume is actual waste, the rest is a surrounding concrete layer in the waste units.
(5) Stored mostly without conditioning in stainless steel containers, drums or other packages.

	Quantities of waste in interim storage (m^3)				
Country	Low level	Medium level	Alpha	High level	Remarks
BELGIUM	6,000	–	3,000	160	Data per 1.5.1990 Medium level waste incl. in low level waste
GERMANY	43,900	(2)	(2)	500	
SPAIN	15,000	–	–	–	Medium level waste incl. in low level waste
FRANCE	0	0	60,400	1,040	Medium level waste incl. in low level waste
ITALY (3)	10,400	720	190	15	
THE NETHERLANDS	3,100				
UNITED KINGDOM	7,930	18,470	65,550	710	Alpha waste are those medium level wastes with an alpha activity >10 GBq/m^3 when in conditioned waste form
DENMARK	700 (4)	50 (5)	–	–	Alpha waste incl. in medium level waste
PORTUGAL	50	–	–	–	
GREECE	100	50	–	–	

TABLE 3
Low and medium level waste disposed of before 1991 with conditioning products and lost package included.

<table>
<tr><th></th><th colspan="4">Quantities of waste (m³)</th></tr>
<tr><th>Country</th><th>Low level</th><th>Medium level</th><th>Type of disposal</th><th>Site</th></tr>
<tr><td>BELGIUM</td><td colspan="2">15,000</td><td>Sea dumping (1)</td><td>N. Atlantic Ocean</td></tr>
<tr><td>GERMANY</td><td colspan="2">96</td><td>Sea dumping(1)</td><td>N. Atlantic Ocean</td></tr>
<tr><td></td><td>42,000</td><td>260</td><td>Deep geological formation</td><td>Asse salt mine(2)</td></tr>
<tr><td></td><td colspan="2">14,300(3)</td><td>Deep geological formation</td><td>Morsleben salt mine</td></tr>
<tr><td>SPAIN</td><td>–</td><td>–</td><td></td><td></td></tr>
<tr><td>FRANCE</td><td colspan="2">9,900</td><td>Sea dumping(4)</td><td>N. Atlantic Ocean</td></tr>
<tr><td></td><td colspan="2">464,500</td><td>Near surface disposal</td><td>Centre de la Manche</td></tr>
<tr><td>ITALY</td><td colspan="2">23</td><td>Sea dumping(1)</td><td>N. Atlantic Ocean</td></tr>
<tr><td>THE NETHERLANDS</td><td colspan="2">8,700</td><td>Sea dumping(1)</td><td>N. Atlantic Ocean</td></tr>
<tr><td>UNITED KINGDOM</td><td colspan="2">26,000</td><td>Sea dumping(1)</td><td>N. Atlantic Ocean</td></tr>
<tr><td></td><td>775,000</td><td>–</td><td>Shallow burial</td><td>Drigg</td></tr>
<tr><td></td><td>14,000</td><td>–</td><td>Shallow burial</td><td>Dounreay</td></tr>
</table>

(1) Moratorium on sea dumping since 1983.
(2) In operation between 1967 and 1978.
(3) Figures up to 1990.
(4) Experimental campaigns in 1967 and 1969.

TABLE 4
Nuclear power programmes in the Member States of the European Community.

	Net power installed at the end of the year (GWe) (Only power stations in operation or committed)				
Country	1990	1995	2000	2010	2020
BELGIUM(1)	5.4	5.4	5.4	5.4	3.6
GERMANY	23.6	23.6	23.6	25.0(2) 17.5	25.0(2) 17.5
SPAIN(3)	7.1	7.1	7.1		
FRANCE(4)	62.7	62.2	[63.3]	[63.3]	[63.3]
ITALY(5)	1.1				
THE NETHERLANDS(6)	0.5	0.5	0.5		
UNITED KINGDOM(7)	11.4	10.0	9.5	5.4	1.2

(1) The general electricity plan applies until 2000; there are no estimates for additional nuclear power plant capacity available after 2000.
(2) 1st line: power stations in operation and with substitution of old stations phased out; 2nd line: *idem*, without substitution.
(3) The present nuclear programme only extends up to the year 2000. No provisions beyond this date are available.
(4) Figures in brackets are given for the sake of homogeneity with similar figures in other countries. They do not take into account the planned power stations figuring in the French Energy Plan's forecast: 63.3 to 66.3 GWe in 2000/74.2 to 80.8 GWe in 2010/and 80 to 95 GWe in 2020.
(5) 1.1 GWe installed, but not in operation.
(6) The development of nuclear power programmes has to be reviewed.
(7) Will be reviewed in 1994.

TABLE 5
Production of low level waste, treated and conditioned in various Community Member States.

(Power stations in operation or committed – assumptions in Table 4, the associated fuel cycle facilities, nuclear energy research.)

(1) Upper and lower estimates.
(2) Possible decommissioning of DR3 research reactor.
(3) A breakdown between waste volume from operating plants (1st figure) and waste volume from plant decommissioning (2nd figure) is given in brackets.
(4) The development of nuclear power programmes has to be reviewed.

	Quantities of waste accummulated per indicated period (m^3)				
Country	1991-1995	1996-2000	2001-2010	2011-2020	Remarks
BELGIUM	3,130	4,230	15,785	15,060	
GERMANY(1)	35,000-50,000	50,000-71,000	97,000 (83,000+14,000)	97,000 (83,000+14,000)	Include partially MLW and alpha waste
SPAIN(2)	11,000	10,000 (8,500+1,500)	17,000 (15,700+1,300)	40,000 (14,600+25,400)	Include MLW
FRANCE	160,000	160,000	300,000	300,000	Include MLW
ITALY(3)	3,100 (3,100+0)	2,700 (1,900+800)	4,300 (3,500+800)	7,000 (500+6,500)	
THE NETHERLANDS	2,400	2,400	–(4)	–(4)	
UNITED KINGDOM(3)	137,530 (104,550+32,980)	106,230 (65,200+41,030)	256,730 (77,360+179,370)	143,330 (12,830+130,500)	Periods: 1990-1994, 1995-1999, etc.
DENMARK	–	–	–	1,500(2)	

TABLE 6
Production of medium level waste of any origin, treated and conditioned, in various Community Member States.

(Power stations in operation or committed – assumptions in Table 4.)

(1) A breakdown between waste volume from operating plants (1st figure) and waste volume from plant decommissioning (2nd figure) is given in brackets.
(2) In accordance with management practices applied in this country, this waste is accounted for in other waste categories.
(3) Waste originating from fuel reprocessed abroad from shut down power plants.
(4) Waste originating from fuel reprocessed abroad from present power plants.

	Quantities of waste accumulated per indicated period (m^3)				
Country	1991-1995	1996-2000	2001-2010	2011-2020	Remarks
BELGIUM(1)	2,500 (2,450+50)	2,754 (2,704+50)	6,724 (6,624+100)	5,730	
GERMANY	–	–			(2)
SPAIN	–	–	–	–	(2)
FRANCE	–	–	–	–	(2)
ITALY	205	120	275		(3)
THE NETHERLANDS	–	250	250	–	(4)
UNITED KINGDOM(1)	12,240 (7,240+5,000)	11,540 (6,400+5,140)	23,010 (11,560+11,450)	18,100 (6,270+11,830)	Periods: 1990-1994, 1995-1999, etc.
DENMARK	100	5	5	–	Incl. alpha waste

TABLE 7
Production of alpha waste treated and conditioned, in various Community Member States.

(Power stations in operation or committed – assumptions in Table 4.)

Country	Quantities of waste accumulated per indicated period (m^3)				
	1991-1995	1996-2000	2001-2010	2011-2020	Remarks
BELGIUM	190	540	2,890	2,430	
GERMANY(1)	–	–	–		
SPAIN	–	–	–	40	
FRANCE	13,640	14,060	36,110	36,110	
ITALY					(2)
THE NETHERLANDS	10	60	70	20	(3)
UNITED KINGDOM(4)	16,350 (12,000+4,350)	18,620 (14,230+4,390)	20,470 (11,960+8,500)	9,550 (1,080+8,470)	Periods: 1990-1994, 1995-1999, etc.

(1) In accordance with waste management practices applied in this country, this waste is accounted for in other waste categories.

(2) No noticeable amount is estimated to arise from nuclear energy research activitiy.

(3) Including waste originating from fuel reprocessed abroad from present power plants.

(4) A breakdown between waste volume from operating plants (1st figure) and waste volume from plant decommissioning (2nd figure) is given in brackets.

TABLE 8
Production of high level waste treated and conditioned in various Community Member States.

(Power stations in operation or committed – assumptions in Table 4.)

Country	Quantities of waste accumulated per indicated period (m^3)				
	1991-1995	1996-2000	2001-2010	2011-2020	Remarks
BELGIUM	45	54	180	180	
GERMANY(1)	1,310-1,510	1,310-1,510	2,620-3,020(2)	2,620-3,020(2)	
SPAIN	–	–	–	36	
FRANCE	510	540	1,980	2,190	
ITALY(3)	10	5	25	–	
THE NETHERLANDS(4)	–	20	25	–	
UNITED KINGDOM(5)	170	260	130	–	Periods: 1990-1994, 1995-1999, etc.

(1) Upper and lower estimates. This category includes partially medium level and alpha waste.

(2) Extrapolated from figures given for the period up to 2000.

(3) Waste originating from fuel reprocessed abroad from shut down power plants.

(4) Waste originating from fuel reprocessed abroad from present nuclear power plants.

(5) Solely from the reprocessing of UK fuel.

TABLE 9
Spent fuel discharged in the member states of the European Community.
(Power stations in operation and/or committed – assumptions in Table 4.)

Country	Reactor type*	Up to end 1990	1991-1995	1996-2000	2001-2010	2011-2020
			Quantity of fuel discharged per indicated period (MTHM)[1]			
BELGIUM	LWR	850	550	550	1,100	770
GERMANY	LWR	3,865	2,450	2,215	4,500[2]	5,500[2]
					4,100	3,200
SPAIN	LWR	975	800	855	1,510	1,090
	GGR	445	447	–	–	–
FRANCE	LWR	6,650	5,120	5,330	10,820	11,000
	GGR	4,340	1,850	–	–	–
	FBR	–	65	72	140[3]	140[3]
ITALY[4] [5]	LWR	342	137			
	GGR	1,353	73			
THE NETHERLANDS	LWR	75	75	75	[4]	[4]
UNITED KINGDOM	GGR		4,000	4,000	2,300[6]	
	AGR		1,100	1,200	1,500[6]	
	LWR		–	150	150[6]	[3]
	FBR					
DENMARK		0.2	0	0	0	0

(1) MTHM: Metric tons of heavy metal.
(2) 1st line: Power stations in operation, with substitution of old stations phased out; 2nd line: *idem*, without substitution.
(3) These data concern reactors in operation, and do not presume decisions on the future of FBR.
(4) 1.1 GWe installed, but not in operation. The development of nuclear power programmes has to be reviewed.
(5) Discharge planned to be completed in 1991.
(6) Data is only available up to 2005.

* LWR: Light Water Reactor
GGR: Gas Graphite Reactor
AGR: Advanced Gas-Cooled Reactor
FBR: Fast Breeder Reactor

TABLE 10
Annual expenditures involved in radioactive waste R&D activities.
Million ECU.

Country	1987[1]	1990
BELGIUM	9.5	11
DENMARK	0.6	0.3
FRANCE	48[2]	85
GERMANY	55	57
GREECE	0.1	0.1
IRELAND	0	0
ITALY	10	5
LUXEMBOURG	0	0
THE NETHERLANDS	4.3	3.6
PORTUGAL	0.1	0.1
SPAIN	4.5	7.5
UNITED KINGDOM	56	63
CEC	15	20

(1) Only CEA.
(2) Ref: *The nuclear fuel cycle: Review on R&D policies in the Member States of the European Community – EUR 12380* (1987).

TABLE 11

Executive bodies responsible for all or part of radioactive waste management in the Community Member States.

(See page 39 for meaning of abbreviations.)

Country	Executive body	Waste conditioning	Laying-down of specifications and quality criteria	Quality control	Site studies, design, construction and management of disposal centres	Studies on management strategies	Transport of waste	Interim storage away from the production installations
BELGIUM	ONDRAF/ NIRAS **public** set up 80-81	In parallel with the industrial operators	√	√	√	√	√	√
DENMARK	The Risø national laboratory, by agreement with the National Health Service, is responsible for collecting and storing radioactive waste from hospitals and industry		Inspectorate of Nuclear Installations					
GERMANY	BfS The "waste" task was assigned to this **federal** body in 1976	(Responsibility of the industry)	√ BfS	√ BfS	√ (DBE acts on behalf of BfS)	√	Performed by industry after permit from BfS	By industry and/or federal centres (Landessammelstellen)
FRANCE	ANDRA **public** set up on 07.11.79	(Responsibility of the industry)	√	√	√	√	√ (partially)	
SPAIN	ENRESA[1] **public** set up in 1984	√ (in particular cases and circumstances)	√	√	√	√	√	√
GREECE	The management and storage are the task of the ministries concerned in cooperation with the Atomic Energy Commission and the Demokritos Research Centre							
IRELAND	The Nuclear Energy Board is responsible for the regulation of the storage and disposal of radioactive waste arising from industry, research laboratories and hospitals in accordance with Statutory Instrument 166/1977							
ITALY	NUCLECO[2] **Semi-public** set up in 1981	Waste producers (ENEA & ENEL) and NUCLECO	ENEA-DISP (Directorate for Nuclear Safety and Radiation Protection)	ENEA-DISP	Site management	ENEA	Commercial operators (under ENEA-DISP control)	√ (for waste from medical, industrial and research activities)
THE NETHERLANDS	COVRA **private** set up in Dec. 1982	√[3]	√	√			√[3]	√[4]
PORTUGAL	The collection, packaging and storage of radioactive waste from research laboratories, hospitals and industry are carried out by the Department of Radiological Protection and Safety of the Laboratório Nacional de Engenheria e Tecnologia Industrial (LNETI) in Sacavém. National competent Authorities are the General Directorate for Primary Health Care of the Ministry of Health (Decree-Law No 348/89 of October 12, 1989) and the Nuclear Safety and Protection Office of the Ministry of Environment (Decree-Law No 425/91 of October 30, 1991)							
UNITED KINGDOM	UK NIREX Ltd set up in July 1982 and made into a limited company wholly owned by the Government in 1985	Waste producer	√[5]	√[5]	√[5]	Waste producers	Nuclear operators	BNFL, AEA NE, SN

(1) Including spent fuel.

(2) Solely in the case of low and medium level waste (waste operator for providing conditioning services).

(3) In the case of interim storage of low and medium level waste.

(4) New facilities for interim storage and treatment of low and medium level wastes at Borsele were completed in 1992.

(5) Solely in the case of low and medium level waste.

√ Role covered by the Executive Body.

TABLE 12
Supercompactors in EC Member States.
(In operation or committed.)

(1) Dependent on waste feed physical form. Lower range values refer to pre-compacted material.

Country and location	Type	Maximum force	Waste stream	Typical volume reduction(1)
FRANCE				
Waste repository				
Centre de l'Aube	Fixed	1,000T	Misc LLW	2-5
Reprocessing plants				
La Hague AD2	Fixed	1,500T	Misc LLW	2-16
Nuclear power plant				
Bugey	Fixed	2,000T		
GERMANY				
Power plant				
Brunsbüttel	Mobile	2,000T	Misc LLW (180 litre drums)	3-4
Research centres				
Karlstein and Karlsruhe	Fixed	1,500T	Misc LLW (180 litre drums)	3-10
Gesellschaft für Nuklear Service, Essen, various	Mobile	1,500T	Misc LLW (220 litre drums)	3-10
ITALY				
Research centre/ waste processor				
Casaccia	Fixed	1,500T	Misc LLW	3-6
NUCLECO, various	Mobile	2,000T	Misc LLW (220 litre drums)	3-6
THE NETHERLANDS				
Waste processor Petten	Fixed	1,500T	Misc LLW (100 litre drums)	5-10
SPAIN				
Various	Mobile	1,200T	Misc LLW	3-6
UNITED KINGDOM				
Drigg	Fixed	–	Misc LLW	–
Dounreay	Mobile	2,000T	Misc LLW	5-10
BELGIUM	Mobile	–	Misc LLW	–
	Fixed	Operational in 1995		

TABLE 13
Large scale incinerators in the EC Member States.
(In operation or committed.)

Country and location	Status	Waste stream	Design capacity
BELGIUM Mol	In operation	Low level beta gamma solid waste + minor quantities of liquids	80 kg/h
Mol	Will substitute the previous one	*Idem* + limited quantities of very low level alpha waste	80 kg/h
FRANCE			
Marcoule	Committed	Misc solids	80 kg/h
Fontenay-aux Roses	In operation	Animal carcasses	50 kg/h
Pierrelatte	In operation	Oil and solvents	70 kg/h
Cadarache	In operation	Spent solvents	30 kg/h
Cadarache	In operation	Pu contaminated solids	30 kg/h
Grenoble	In operation	Organic products	15 kg/h
GERMANY			
Karlsruhe	In operation	Alpha solids	50-60 kg/h
Karlsruhe	In operation	Misc solids (beta/gamma)	50 kg/h
Karlsruhe	In operation	Liquids	50 kg/h
Jülich	In operation	Low level liquid wastes	20 kg/h
Jülich	In operation	Low level solid wastes	50 kg/h
SPAIN El Cabril	Committed	Low level waste, mainly organic and biological wastes	50 kg/h
UNITED KINGDOM			
Hinkley Point and Wylfa	In operation	Misc solids Contaminated oil	75 kg/h 20/30 l/h
Harwell	In operation	Solid low level waste	136 kg/h
Dounreay	In operation	Mainly solid	3,000 m^3/y

TABLE 14
Interim storage of vitrified high level waste within the European Community.

Country	Facilities	(Available capacity in m^3)	Duration of interim storage	Date of operation
FRANCE	Marcoule	440	30y	1978
		160		1996
	La Hague	900	30 y	June 1989
		720		1996
UNITED KINGDOM	Sellafield	1,200	At least 50 y	February 1991
BELGIUM	Dessel 1) Eurochemic	250	At least 30 y	1986
	2) La Hague	75	At least 50 y	1993
THE NETHERLANDS	Borsele	60	100 y	2000
GERMANY	Gorleben	To be defined	At least 15-20 y	Still not defined
SPAIN	— (1)		40 y	— (2)
ITALY	— (3)		—	1994

(1) Will be defined at the turn of the century.
(2) Vitrified waste will be returned after 2010.
(3) ENEL's vitrified wastes will probably be stored at a shut down power station.

TABLE 15
Interim storage of low and medium level radioactive waste packages within the European Community.

Country	On-site	Centralised site	Remarks
SPAIN	Yes	Yes	The El Cabril facility should progressively receive waste packages still stored on-site
THE NETHERLANDS	Yes (provisional)	Yes	The Borsele interim storage facility is equipped for receiving reactor and reprocessing wastes as well
BELGIUM	No	Yes	All kinds of waste generated in Belgium are stored in Mol/Dessel. An extension of the building's capacity for storing reprocessing wastes should be completed by 1993
UNITED KINGDOM	Yes	No	Interim storage only concerns those waste types which do not comply with the disposal criteria for the Drigg near surface site
FRANCE	Yes	Yes (for LLW arising from small producers)	As in the UK case, interim storage only concerns those waste types which cannot be disposed of in a near surface site (Centre de la Manche and Centre de l'Aube)
GERMANY	Yes	Yes (Gorleben and Mitterteich facilities)	Once a disposal facility for L & MLW is available, only centralised interim storage sites will be operated
ITALY	Yes	No	
PORTUGAL	No	Yes	
GREECE	No	Yes	
DENMARK	No	Yes	

TABLE 16
Storage capacities for spent fuel (tons of heavy metal).

(1) Extension of capacity is under study.
(2) Away from reactor.
(3) Additional full core discharge capacity is available.
(4) Including reprocessing plants and power plants.
(5) Beyond this date, additional capacity will be provided as required.

Country	1990	1995	2000
BELGIUM	1,350	1,350(1)	1,350(1)
GERMANY	3,000(2)	3,000(2)	3,000(2)
SPAIN(3)	1,950	4,030	4,170
FRANCE(4)	13,000	20,400	21,000
ITALY	590	590	580
THE NETHERLANDS	0	0	0
UNITED KINGDOM	8,300	8,300(5)	8,300(5)

ABBREVIATIONS

AEA	Atomic Energy Authority
ANDRA	Agence nationale pour la gestion des déchets radioactifs
BfS	Bundesamt für Strahlenschutz
BNFL	British Nuclear Fuels plc
CEA	Commissariat à l'énergie atomique
CEC	Commission of the European Communities
CEGB	Central Electricity Generating Board
CEN/SCK	Centre d'étude de l'énergie nucléaire/Studiecentrum voor Kernenergie
CIEMAT	Centro de Investigaciones Energeticas, Medio Ambientales y Technologicas
COVRA	Centrale Organisatie Voor Radioactief Afval
CSN	Consejo de Seguridad Nuclear
DBE	Deutsche Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe
EC	European Community
ENEA	Ente per le Nuove Technologie, l'Energia e l'Ambiente
ENEL	Ente Nazionale per l'Energia Electrica
ENRESA	Empresa Nacional de Residuos Radioactivos
HLW	High level waste
IAEA	International Atomic Energy Agency
LLW	Low level waste
MLW	Medium level waste
NAGRA	Nationale Genossenschaft für die Lagerung radioaktiver Abfälle
NE	Nuclear Electric
NEA	Nuclear Energy Agency
NIREX	Nuclear Industry Radioactive Waste Executive
NUCLECO	Nucleare-Ecologia
ONDRAF/ NIRAS	Organisme national des déchets radioactifs et des matières fissiles/ Nationale Instelling voor het Beheer van Radioactief Afval en Splijtstoffen
OECD	Organisation for Economic Co-operation and Development
OPLA	Opslag op Land
PTB	Physikalisch-Technische Bundesanstalt
SN	Southern Network
WAK	Wiederaufarbeitungsanlage Karlsruhe
WHO	World Health Organisation

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