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COMMUNICATION AND FOURTH REPORT FROM THE COMMISSION

on:

The Present Situation and Prospects for Radioactive Waste Management in the European Union

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CONTENTS

1. Introduction

In its resolution of 18 February 1980[1], the Council approved a Community Action Plan in the field of radioactive waste for 1980 to 1992. This Plan was extended to the end of 1999 by the Council's Resolution of 15 June 1992. In its renewal of the Plan, the Council considers that the 1980-1992 Plan "has been successful" and that current Community activities on technical, legal, and administrative issues of radioactive waste management "should be continued and expanded".

Point 1 of the Plan requires continuous analysis of the situation regarding radioactive waste in the European Union, and the Commission is requested to provide the Council periodically with an analysis of the situation and prospects in the Member States. The European Parliament is to be kept informed.

In 1983, 1987 and 1993 the Commission forwarded reports[2] that included forecasts to the end of the century in the 1983 and 1987 reports, and to 2020 in the 1993 report.

The Commission forwards as an annex to this Communication its fourth report based on the 1997 situation and compiled in the same manner as the previous reports from information provided by the Member States.

2. Present situation and prospects

Radioactive waste is generally understood as material for which no further use is foreseen, and which has been managed in a system of reporting, authorisation and control as specified in international recommendations, or Community or national legislation. The report is mainly concerned with radioactive waste within the system of control. Additionally, it addresses wastes from industrial processes involving concentration of natural radionuclides and residues from enrichment of uranium, both of which are not formally considered as *radioactive* waste.

Processes and techniques used in the management of all categories of radioactive waste have been developed to a point where they can be applied on the industrial scale. The only aspect yet to be put into practice is the deep disposal of high-level heat-generating waste. Though the technical feasibility has been demonstrated in extensive experimental research and numerous related studies, its realisation is delayed in some Member States owing to difficulties in licensing and problems of public perception.

In addition, the full decommissioning of nuclear installations is feasible and has been demonstrated in large-scale pilot dismantling projects.

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1 see O.J. N° C51/1-2-3 of 29/02/1980

2 Communications from the Commission to the Council "First report on present situation and outlook for radioactive waste management in the Community", doc. COM(83) 262 of 16/05/1983, "Second report", doc. COM(87)312 of 29/07/1987 and "Third report", doc. COM(93)88 of 01/04/1993.

2.1. Radioactive waste streams

All Member States have radioactive waste arisings, even if quantities of waste needing long-term storage and disposal are very small in countries without nuclear energy production capacity. Radioactive waste results mainly from four types of activity:

- nuclear electricity generation, including back-end nuclear fuel-cycle activities and decommissioning;
- the operation of research reactors;
- the use of radiation and radioactive material in medicine, agriculture, industry and research;
- processing of material containing natural radionuclides.

The annexed report provides details of the arisings from the first three activities in five-year periods up to year 2020, and contains general information on the fourth activity. The figures take into account only production from facilities already in operation, under construction, or firmly committed, and are probably close to the minimum quantities to be expected. The report distinguishes between low and intermediate level waste (non-heat generating) of both short (up to 30 years) and long half-life, high-level waste, which includes vitrified residues from reprocessing, and conditioned spent fuel declared as being radioactive waste. All quantities refer to solidified waste, conditioned for disposal. Figures for quantities of untreated waste have been adjusted by supposing the most probable treatment process in order to provide a coherent set of data.

For Member States without a nuclear power program, annual arisings of radioactive waste requiring storage and disposal are low, typically 0.5 m^3 per million inhabitants, though this may rise to 10 m^3 per million inhabitants in those countries operating research reactors.

Nuclear power plants in the European Union are predominantly light water reactors of about 1,000 MWe capacity. Typically, such plants produce annually about 100 m^3 of operational waste of the short-lived type, with arisings as low as 50 m^3 for the most recent plants. Spent nuclear fuel discharged from an 'average' reactor totals 20 to 30 tonnes of heavy metal annually, depending on enrichment of the fuel and availability of the plant. Decommissioning of an 'average' nuclear power plant would result in the production of about 10,000 m^3 of radioactive waste, but since decommissioning is, in most cases, delayed for decades, only a small percentage of the resulting waste is included in the figures in the report. However, greatly increased waste arisings from decommissioning can be expected for the period 2020 to 2050.

From the annexed report, the predicted annual production of conditioned radioactive waste (all categories) in the European Union is approximately 50,000 m^3, somewhat less for the period to the year 2000, and somewhat more thereafter. After the year 2000, a decrease in arisings owing to the closure of old plants is compensated by increased arisings from dismantling of nuclear installations. These totals represent a dramatic reduction compared with figures presented in the previous (third) report, where values of 80,000 m^3/year were being predicted for the European Union as a whole. Furthermore, that report did not take into account arisings in Austria, Finland and Sweden, which were not Member States at that time. The reasons for the reduction are: construction of new power plants has all but halted (the exception being France); a number of older plants have been closed down definitively; nuclear power plant operators have made tremendous efforts to reduce waste production at source; and advanced waste volume reduction techniques are being applied.

Reprocessing of spent reactor[1] fuel followed by vitrification of fission products is performed commercially in France and the United Kingdom. Some of the spent fuel they reprocess originates from other Member States. Three Member States, Finland, Spain and Sweden, have decided to condition all spent fuel for direct disposal, and others are also preparing for the disposal of some types of spent fuel without reprocessing. However, the recycling of reprocessed plutonium and uranium in light-water-reactors through the production of mixed-oxide (MOX) fuel is now established technology. On the other hand, the option of recycling these fissile materials in fast-breeder reactors will not now be available in the short or medium term.

2.2. Storage and disposal

Storage of radioactive waste has become a routine matter. In a marked development since the previous report, a few Member States are now completing or have put into operation central storage facilities for returned vitrified waste following reprocessing or for spent fuel destined for direct disposal.

Those Member States with no nuclear power production capacity have abandoned, for the time being at least, plans for disposal of their radioactive waste. Additionally, three countries with nuclear power production plants, Italy, the Netherlands and the United Kingdom, have decided to postpone disposal of high-level waste for periods ranging from at least fifty to possibly more than one hundred years.

Radioactive waste disposal has been practised by all Member States with a nuclear power plant programme. Until the end of 1994, a total of 1,640,000 m^3 had been disposed of, either by ocean disposal (until 1982), by surface and shallow disposal, or by deep geological disposal. Finland, France, Spain, Sweden and the United Kingdom operate surface and shallow disposal facilities for radioactive waste containing only small quantities of long-lived radionuclides. Germany operates a deep disposal facility in a former salt mine.

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1 A discussion of reprocessing and use of recycled uranium and plutonium is included in the Commission's recently adopted PINC illustrative programme document COM(97)401 final of 25/9/97.

Long-lived heat-generating waste is stored on the surface until deep facilities for their disposal become available. A number of Member States are involved in preparatory work for disposal of this type of waste, such as operating underground laboratories, seeking sites or preparing licensing.

2.3. Other aspects of radioactive waste management

Funding for research and development in the field of radioactive waste has decreased gradually during recent years, mainly because most processes and techniques have now been developed to a point where they can be applied on an industrial scale. The only aspect that is still to be realised is the actual disposal of high-level heat-generating waste, together with the definition and adoption of safety indicators valid over very long periods of time. Some of the available funding is now devoted to more fundamental research topics, such as advanced radionuclide separation techniques and transmutation of long-lived radionuclides. All Member States with a nuclear power program have set up agencies responsible for all or part of the management of radioactive waste. Control of the activities of these agencies is entrusted to safety authorities. The annexed report provides some information on costs of the various steps in the management of radioactive waste. For example, disposal of non-heat-generating waste costs a few thousand ECU/m³, whereas disposal of high-level waste will be much more costly. Repositories for high-level waste are expected to cost between 2 and 4 billion ECU regardless of the waste quantities involved. The financing of the back-end of the nuclear fuel cycle can be achieved in different ways, but in most Member States the financing is via the earmarking of a portion of the electricity price, which is then set aside for this purpose.

All Member States of the European Union have nuclear laws, regulations and standards on radiation protection and to some extent on control of radioactive waste management. European Community legislation is applicable in particular in the areas of safety standards in radiation protection, control of shipments of radioactive material, and on safeguards for fissile material which may be present in waste or spent fuel declared as being waste. Environmental impact assessments are required for radioactive waste disposal installations as laid down in Directive 85/337/EEC, as amended by Directive 97/11/EEC.

At the global level, the International Convention on the safety of spent fuel management and the safety of radioactive waste management has been open for signature by contracting parties since September 1997. At the end of February 1998, the Convention had been signed by the following Member States: Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Sweden and UK.

3. COMMISSION ACTION

This communication is part of the renewed Plan of Action in the field of radioactive waste. In this framework, the Commission formulated in 1994 the "Community strategy for radioactive waste management"[1]

The strategy is basically oriented towards public safety and environmental protection. Its approach is one of harmonisation at Community level, where practicable, of radioactive waste management principles and practices to ensure an equivalent and acceptable level of safety throughout the European Union. It represents a comprehensive medium to long term programme calling for a step by step approach for its future implementation. It concentrates on a number of main elements that could benefit from a common approach at Community level. These are: the definition and classification of radioactive waste; the minimisation of waste; the transport of radioactive waste; the treatment and disposal of waste; public information; and the financing of radioactive waste management.

In its Resolution on Radioactive Waste Management of December 1994[2], the Council welcomed the Community Strategy and called upon the Commission to continue its work in the area with the assistance of the Consultative Committee set up for the Plan of Action. It also specifically requested the Commission to continue its work on determining the conditions for recycling and re-use of materials with low level of radioactive contamination; reaffirmed the importance of pressing on with efforts to reduce the volume and radiotoxicity of radioactive waste; suggested that further consideration be given to various approaches which might result in the minimisation of transport of radioactive waste; emphasised the need for the public to be objectively informed regarding the management of radioactive waste and invited the Commission to continue and, where appropriate, intensify its efforts to that end. A number of topics addressed as "actions" in the Strategy have been subject to studies by external organisations and to expert assessments in specialised working groups. The results are made available in the form of technical reports, and the Commission is planning communications based on these studies. These are: the financing of radioactive waste management activities; radioactive waste categorisation and equivalence; the management of sealed sources; and the management of wastes containing enhanced concentrations of natural radionuclides. One or more of these communications could form the bases for draft Council Directives.

Within the Community's research and development program on nuclear fission safety (1994-1998) most of the work on radioactive waste management is devoted to the further development and the consolidation of the long-term safety assessment methodology as well to its application on different sites, concepts and radioactive waste inventories. The program also supports the operation of underground research facilities, which provide samples and data and establish the feasibility of future repositories. Advanced partitioning and transmutation of long-lived radionuclides,

1 Communication COM(94)66 final of 2/3/1994

2 Official Journal of the E.C. 94/C 379/01 of 19 December 1994

with particular attention to plutonium and americium, are important study subjects. Research on decommissioning of nuclear facilities within the 1994-1998 R&D program is limited mainly to some improvements in decommissioning technology, and testing and demonstration of decommissioning techniques in full-scale dismantling.

In the Community legislation, a recent event was the adoption by Council of the 1996 revision of the Basic Safety Standards for the protection of health of the general public and workers against the danger of ionising radiation. The provisions of the Directive[1] have to be implemented in national law before 13 May 2000. Items of particular importance to radioactive waste management are lower dose limits for public and workers, and radionuclide specific reporting levels. Another important element is the adoption by Council of an amendment to the Directive requiring Environment Impact Assessments. The amendment[2] requires an assessment not only for radioactive waste repositories, but also for storage facilities with a planned storage duration in excess of 10 years. The provisions of this amendment have to be introduced in national legislation by 14 March 1999.

4. RECOMMENDATION

The attention of the Council is drawn to a number of areas where, in the Commission's opinion, further action by the Member States and the Commission is needed.

- The Member States are encouraged to continue their activities concerning the siting, construction, operation and closure of high-level waste repositories in deep clay, granite or salt formations. One of the main problems is the lack of acceptance by the public for any specific site in their neighbourhood. A better programme of public information may help to overcome this lack of acceptance, and the Commission will continue to provide information to this purpose.

- Through its support of the work undertaken by the radioactive waste management agencies in establishing a safety case for a deep repository, the Commission has become aware of the difficulties in getting the work accepted by the safety authorities. It is therefore recommended that, as far as possible, the national safety authorities be included in preparatory work prior to requests for licensing of such repositories, and that co-operation between the safety authorities of the Member States be actively encouraged.

- Member States are encouraged to continue their efforts to reduce the volume of waste arisings from all nuclear applications, both through measures to reduce volumes at source and by application of advanced waste volume reduction techniques. To this end, there should be exchange of information at the

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1 Directive 96/29/EURATOM of 13 May 1996

2 Directive 97/11/EEC of 3 March 1997

Community level on developments in waste volume reduction practices for the different waste types.

- As a result of decontamination or simple radioactive decay, even large quantities of declared radioactive waste will eventually exhibit very low levels of residual radioactivity. Indeed, following the dismantling of nuclear installations, a large quantity of material may even be totally free of artificial (i.e. man-induced) radioactivity. Clearance levels for this material do exist, but often only on a case-by-case basis. It is important to achieve a common set of rules at Union level for the clearance, either conditional or unconditional, of this material. The present situation, where some countries have clearance levels and others do not, with the resulting implications for the release and circulation of the material within the market, is clearly not satisfactory.

- The Commission repeats its plea, voiced in the Strategy, for self-sufficiency of the European Union as a whole and solidarity between Member States in matters of radioactive waste disposal. As in the strategy for non-radioactive waste the Union should aim for self-sufficiency, even if transfer to countries outside the Union is not excluded in Community legislation on control of shipment of radioactive waste. Some Member States have included self-sufficiency at national level in their legislation, barring entry of foreign waste for disposal. Countries with a large radioactive waste production certainly should be able to dispose of their waste on their own territory. The possibility of voluntary co-operation between Member States however should be kept open, where, for example, a regional approach to disposal could result in improved safety and environmental benefits.

- Finally, research and development should continue in radioactive waste management with the aim of improving data, models, and concepts related to long-term safety of disposal of long-lived (and particularly heat-generating) waste. Research in the area of advanced partitioning and transmutation should also continue.

EUROPEAN COMMISSION
DIRECTORATE-GENERAL XI
ENVIRONMENT, NUCLEAR SAFETY AND CIVIL PROTECTION
Directorate C - Nuclear safety and civil protection
XI.C.2 - Radioactive waste management policy

FOURTH REPORT FROM THE COMMISSION

on:

The Present Situation and Prospects for Radioactive Waste Management in the European Union

PREFACE

The Community Plan of Action in the field of radioactive waste for 1993-1999, approved by the Council of Ministers of the European Communities in June 1992[1], provides under point 1 for continuous analysis by the Commission of the situation regarding radioactive waste management in the European Union.

To enable the Community and the Member States to make use of the results of such an analysis, the Commission periodically reports to the Council of Ministers.

Reports were forwarded to the Council in 1983[2], 1987[3] and 1993[4]. The present report is thus the fourth of its kind; it updates and supplements the information presented in the previous reports and for the first time provides information on the situation in the countries which joined the Union in 1995, namely Austria, Finland and Sweden.

The present report is based on information from national sources supplied by Member States' delegates in an ad-hoc working group set up by the Commission's Advisory Committee for the Community Plan of Action in the field of radioactive waste.

General background information on radioactive waste was set out in the previous reports to which the reader may refer to supplement the information presented here.

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1 Council Resolution (92/C 158/02) of 15 June 1992 on the renewal of the Community Plan of Action in the field of radioactive waste.

2 Communication from the Commission to the Council of Ministers of the European Communities, Doc COM(83) 262 final of 16/05/83 "Analysis of the present situation and prospects in the field of radioactive waste management in the European Community."

3 Communication from the Commission to the Council of Ministers of the European Communities, Doc COM(87) 312 final of 29/07/87 "Analysis of the present situation and prospects in the field of radioactive waste management in the European Community. Second Report"

4 Communication from the Commission to the Council of Ministers of the European Communities, Doc COM(93) 88 final of 1 April 1993 "Third report from the Commission on the present situation and prospects for radioactive waste management in the European Community."

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1. Introduction and Overview

Waste production is inevitably associated with human activity. Radioactive waste arisings are very small, in terms of volume, in comparison with other industrial waste. Some part of it, in particular high-level radioactive waste from nuclear power production, remains hazardous for thousands of years; it has to be carefully controlled and disposed of by providing barriers delaying return of radioisotopes to the biosphere.

All countries have radioactive waste arisings resulting from use of radionuclides in medicine, research and industry. Most radionuclides applied in medicine are very short-lived; waste is stored to allow decay and then released when concentrations fall below limits defined in the operating license of, for example, individual hospitals or interim storage facilities. Of particular radiological concern are spent sealed sources, which are normally collected and stored at a central facility.

By far the highest quantities of radioactive waste are produced in the nuclear fuel cycle, where the largest volumes arise in uranium mining and milling, and in uranium enrichment. Waste volumes containing enhanced concentrations of natural radionuclides are not normally registered as radioactive wastes, but they may, under certain circumstances and if badly managed, present a radiological risk and be chemically toxic.

The expected production of radioactive waste, compared with the volumes predicted for specific countries in earlier reports, has diminished considerably. The main reason is that the construction of new power plants has been halted in most Member States as a consequence of policy revisions following the Three Mile Island accident in 1979 and in particular the Chernobyl-4 accident in 1986. Another reason is that a number of first generation and demonstration power plants have been definitively shut down. Furthermore, the power plant operators have made great efforts to reduce waste production at source, to use filters more efficiently, and to apply advanced waste conditioning methods aimed at volume reduction.

The present report distinguishes between the categories 'high-level waste' (almost exclusively the vitrified residues from reprocessing of spent fuel) and 'spent fuel destined for direct disposal'. In the previous report, most country forecasts for high-level waste arisings assumed the reprocessing of spent fuel to be the dominant management route. Only Spain had declared its light-water reactor spent fuel as radioactive waste, while other Member States had categorised only 'special' (i.e. not readily reprocessible) fuel as radioactive waste. However, with Finland and Sweden now Member States since 1995, direct disposal of conditioned spent fuel is no longer a marginal management route within the European Union.

Full decommissioning of nuclear installations is feasible and has been demonstrated by large-scale pilot dismantling projects. Nevertheless, the large majority of installations would first be left in a 'safe storage' condition, allowing decay of radionuclides over decades or even centuries, depending on national practices. For this reason, contributions to radioactive waste arisings from dismantling do not appear in most forecasts until 2020 at the earliest.

Application of radionuclides in the military sector, mostly in lighting devices and emergency power sources, contributes to small additional radioactive waste quantities in the national inventories. Only France and the United Kingdom, which have developed and maintain nuclear weaponry and operate nuclear powered submarines, have sizeable associated radioactive waste quantities.

This present report also addresses the problem of radioactive waste containing chemically toxic substances. Under certain circumstances, such waste may require deep disposal even though from radiological considerations alone it would be suitable for on-surface disposal. Another item discussed is uranium residues from reprocessing, or from re-enrichment of reprocessed uranium; according to policy in the Member States, these are not considered as radioactive waste.

1.1 Radioactive waste quantities

Quantities of relatively long-lived radioactive waste requiring storage and disposal emanating from medicine, research and industry are low; volumes range from 0.1m^3 to slightly over 1000 m^3 annually for large Member States. Typically, 0.5 m^3 per million inhabitants per year are produced, which rises to within the range 4 to 10 m^3 per million inhabitants per year for states with research reactors and isotope producing nuclear reactors.

Radioactive waste arisings from operation of nuclear power plants depend heavily on reactor type, mode of operation, availability and year of construction, as well as on the waste management strategy, i.e. re-use and/or recycling of slightly activated or contaminated substances. About half of the total EU capacity is installed in France; the dominant reactor-type is the pressurised-water reactor, and average electricity generation capacity is 1000 MWe. Such a plant would produce up to or slightly more than 100 m^3/year of normal operational waste, the vast majority of which is suitable for near-surface disposal (half-lives of 30 years or less and very small quantities of alpha-emitters). About 20 to 30 tonnes of heavy metal (tU) would be discharged annually from the reactor, which would then be stored mostly in the reactor-pool for three to five years. Decommissioning waste arisings depend of course heavily on the type of installation and on the criteria set up by safety authorities concerning conditional and unconditional release of very low-level radioactive material.

Waste arisings are discussed in detail in Chapter 2, and totals for each Member State are presented in the associated tables. These totals reflect the particular situation in each Member State and are not necessarily directly comparable.

1.2 Treatment and conditioning

Treatment and conditioning techniques are applied on an industrial scale, and progress has been made in reducing waste volumes through incineration, supercompaction and reduction in the added amounts of typical conditioning materials such as cement or concrete.

Major developments, which are a consequence mainly of policy modifications, can be observed in the strategy for treating spent fuel. In Member States with nuclear power production, the following strategies exist:

- storage of spent fuel for an undetermined time;
- reprocessing of spent fuel, direct or intended later use of uranium and plutonium in reactors, later disposal of vitrified residues;
- conditioning for direct disposal of spent fuel.

Some Member States have adopted a mix of these strategies.

To give an idea of the quantities involved, consider first the volume of waste resulting from the reprocessing of 30 tonnes of spent fuel (typical annual discharge from a 1000 MWe reactor). Considering just two categories, waste requiring deep disposal and waste suitable for on-surface disposal, ranges of volumes of 15 to 36 m^3 in the former category and 20 to 92 m^3 in the latter are quoted, depending on the precise technology used in the treatment of a particular waste stream (e.g. degree of compaction of low-level waste etc.), the criteria defining the deep and on-surface disposal categories, when in the future the disposal takes place, and so on. In comparison, the conditioning of 30 tU of spent fuel for final disposal following the German concept (by disassembling the fuel element) results in approximately 30 m^3 of high-level heat-generating radioactive waste, associated with 13 m^3 suitable for on-surface disposal (EUR-13389 "Radioactive Waste Management and Disposal - Proceedings of the 1990 EC-Conference"). The Swedish conditioning concept would produce 55.5 m^3 of heat-producing radioactive waste for 30 tU of spent fuel.

Plutonium and uranium from reprocessing were initially intended for use in the production of fast-breeder fuel assemblies. However, as a fast-breeder reactor programme no longer appears to be a possibility in the short or medium term, the production of MOX (mixed oxide) fuel has become the preferred management route for at least some of this material.

1.3 Storage and disposal

Storage of radioactive waste is now a routine matter. Some Member States have completed or are preparing storage facilities for vitrified high-level waste returning from the reprocessing facilities in France and the United Kingdom. Other Member States have centralised facilities for storage of spent fuel, e.g. CLAB (Sweden) and Brennelement Lager Gorleben (Germany).

Disposal of low- and medium-level non-heat-generating radioactive waste is now a rather common practice in Member States with a nuclear power production programme. France, Spain and the United Kingdom operate on-surface facilities, and Finland, Germany and Sweden practice disposal of radioactive waste containing allowed specified amounts of long-lived radionuclides in near-surface or deep geological facilities. Disposal of long-lived, heat-generating waste has not yet been performed, but preparatory work, for example operation of underground laboratories, site selection and site characterisation are progressing in a number of Member States.

It should be noted that all Member States without a nuclear power production plant have abandoned national plans for disposal of radioactive waste for the foreseeable future, and that three countries with power-production plants (Italy, the Netherlands, United Kingdom) have decided to postpone disposal of high-level waste for periods ranging from at least fifty to more than one hundred years.

1.4 Research and development

The nuclear industry, including the integral radioactive waste management part, is a mature industry. Improvements are certainly possible, but funding for R&D is decreasing. The only aspect still to be realised is the disposal of high-level heat-generating radioactive waste, i.e. vitrified waste and spent fuel. In this respect, R&D continues to complement the work on deep geological disposal through on-site studies in underground laboratories. In addition, partitioning and transmutation of long-lived high-level waste is being investigated.

1.5 Operational safety

During the period under consideration between 1993 and February 1997, no incident or accident of radiological significance has been observed in radioactive waste management operations. It is particularly noteworthy that in the area of transport of radioactive waste, which comes under close scrutiny by NGOs and the public, not a single entry is to be found in the INES (International Nuclear Event Scale) database maintained by the International Atomic Energy Agency.

1.6 Radioactive waste management organisations

All Member States have legal provisions especially set up to guarantee safe management of radioactive waste. In countries without nuclear power production, Government bodies or state-owned institutes collect radioactive waste and store it, thus enabling disposal to take place in a possible future facility.

Most Member States with nuclear power production installations have set up agencies or bodies with the task of managing some or all steps of radioactive waste management. These agencies have two common features:

- they are the only agency in that particular country, and even if there is sometimes no formal obligation for producers to use their services, they present the only viable management option;

- State involvement is assured, either through the direct running of the agency, through control at the level of its board of directors, through share ownership, or through ownership of the shareholding companies.

Regulation of the activities of producers and agencies is entrusted to national safety authorities, which are often assisted by Technical Support Organisations (TSO). In Member States with nuclear power production, there can be varying degrees of separation between agencies and safety authorities, but both may be under the control of one ministry.

1.7 Cost, financial schemes and liabilities

Radioactive waste from small producers is sometimes collected, and in most cases conditioned and stored by a central organisation. It is difficult to estimate the costs of radioactive waste management from nuclear fuel cycle facilities owing to enormous differences in management policies, treatment techniques, methods for accounting depreciation and interest rates, discounting, etc. Section 5.1 of this report gives indications of ranges of costs in the different Member States. Treatment and conditioning of radioactive waste from reactor operation is considered as part of the plant operation cost; with high volume reduction the costs for disposal-ready packages can be higher than 10,000 ECU/m^3. Concerning the fuel cycle itself, the reader is referred to the 1994 OECD/NEA study "The Economics of the Nuclear Fuel Cycle" (ISBN 92-64-14154-5) for a detailed examination of the costs of the different fuel cycle components and options. This study concludes that for a 'reference case' PWR the overall cost of the reprocessing option is similar to the cost of direct disposal option. Estimates of transport and storage costs can be found in the report EUR-13389 mentioned in Section 1.2.

Costs for disposal of non-heat-generating waste are known. For example, in the case of on-surface disposal, which is only for radioactive waste with a very low content of long-lived radionuclides, prices ranging from 1200 to 3725 ECU/m^3 have been reported. For underground disposal (shallow depth and deep), a range from 3440 to 6250 ECU/m^3 is stated. Realisation of deep disposal of high-level waste is probably decades away, but estimated costs for such an installation are huge, probably in the 2 to 4 billion ECU range; the corresponding unit costs would reach 350,000 to 1 million ECU/m^3 depending on the quantity of waste for disposal. Decommissioning of nuclear power plants will probably require provisions in the range 12 to 15% of construction costs at constant prices. However, it should be noted that operating nuclear power plants earn large revenues from the sale of electricity, and back-end costs are relatively small in comparison.

Financing schemes differ widely from country to country. One extreme is the case of State-owned and -operated facilities with no provisions, where the general budget will provide cover for costs. A more widely adopted approach is to promote the setting up of funds financed by the power plant operators themselves (through legal obligation or tax incentives). Another popular scheme in the European Union is a fund, operated by the radioactive waste management agency or the Government, fed by a special fee levied on electricity production or by withholding a percentage of the consumer price for electricity.

There are also large differences between Member States regarding the transfer of financial and other liabilities. In some Member States liabilities are transferred to the agency or the State at the moment of delivery of the waste to the appropriate installation, in others the waste producer retains responsibility.

1.8 Institutional and regulatory matters

Legal and regulatory measures are the basis for the system of control of radioactive waste management. An International Convention on nuclear safety, also covering radioactive waste at the power stations, came into force in October 1996, and a Joint Convention on the safety of spent fuel management and the safety of radioactive waste management has been open for signature since September 1997. Safety fundamentals, standards and guides in the field have been prepared under the IAEA's RADWASS-programme.

At Union level, the Plan of Action in the field of radioactive waste allows for co-operation between Member States and the Commission (Council Resolution of 15th June 1992). A Community strategy for radioactive waste management has been adopted by the Commission (COM(94)66) that includes actions on harmonisation (radioactive waste categorisation, equivalence) and a plea for Community solidarity in the disposal of radioactive waste. In its Resolution of 19th December 1994, the Council welcomed the strategy, took the view that each Member State is responsible for management of its own radioactive waste and noted the possibility of mutually agreed co-operation between Member States. Note that a Community strategy for waste management, excluding radioactive waste, exists since 1989 (SEC(89)934), and is currently under revision (COM(96)399); a Council Resolution of 18th May 1990 on this subject will eventually be followed by a Resolution concerning the revised text.

Radiation protection is governed by the Basic Safety Standards (Directive 80/836/EURATOM), of which a revised version (Directive 96/29/EURATOM "The Basic Safety Standards for the Protection of the Public and Workers from Ionising Radiation") has to be implemented in national law before 13th May 2000. Supervision and control of the shipment of radioactive waste (Directive 92/3/EURATOM) and radioactive substances (93/1493/EURATOM) are already implemented in national law. Note that supervision and control of waste shipments are subject to Regulations (259/93/EEC and amendment 120/97/EEC) already in force in the Member States.

All Member States have nuclear laws, regulations and standards on radiation protection and, to a certain extent, on radioactive waste management. It is noteworthy that some Member States (Finland, France, Luxembourg and Sweden) have adopted laws that forbid the importing of radioactive waste for disposal on their territory. Note also that there are still only patchy regulations dealing with the protection of health of future generations. The only commonly applied safety indicator is the expected dose to the public and to workers, though in the Netherlands a risk limit has been specified, and in the United Kingdom a 'risk target' for the long-term consequences of geological disposal has been set.

2. Sources, Categories and Quantities of Radioactive Waste in the EU

Radioactivity is a natural phenomenon and is present at varying background levels in the environment, therefore criteria exist in all Member States that define the thresholds of specific activity and surface contamination above which radioactive waste has to be included in the system of reporting, authorisation and control. This threshold, or reporting level, is specified in the Euratom Directive (80/836 EURATOM) laying down the basic radiation protection standards, and is 100 Bq/g for artificial and 500 Bq/g for natural radionuclides. Radioactive waste, as defined by these thresholds, is the principal subject of the present report.

Since the publication of the Third Report (COM(93)88) a revision of the Basic Safety Standards (Directive 96/29/EURATOM) has been adopted by the Council of Ministers. Together with other important modifications, for example a reduction in the acceptable exposures to workers and members of the public, this document introduces radionuclide-specific reporting levels. Large quantities of waste from industrial processes involving concentration of natural radionuclides will have to be included in a future system of control to be defined by national safety authorities. This report provides indications about the nature and volume of such wastes.

2.1 Sources of radioactive waste arisings

Radioactive waste arisings can result from four types of activity[1]:

- nuclear electricity generation, including various back-end nuclear fuel cycle activities, related research and the decommissioning of obsolete plants;

- the operation of research reactors;

- the use of radiation and radioactive materials in homes, medicine, agriculture, industry and research;

- processing of materials that are naturally radioactive, such as uranium ores and phosphate fertilisers.

The relative importance of these sources varies considerably from one EU country to another, though all EU countries commonly use radionuclides for research, industrial and medical purposes. Those countries with nuclear power programmes generate most of the radionuclide inventory in the waste, and the majority of the radioactive waste in terms of volume, arising in the Union as a whole.

A few countries, both with and without nuclear power programmes, operate uranium mines and mills that generate large volumes of slightly radioactive materials containing natural radionuclides. For several years it has also been

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1 Although military nuclear activities are outside the scope of this report, the radioactive waste arising from them is included in the inventories.

recognised that other industrial activities may generate similar materials. This is the case in industrial activities where raw materials containing naturally occurring radionuclides are processed on a large scale, such as the production of phosphate fertilisers and the extraction of oil and gas for example. These processes have the potential to produce waste materials or by-products with a significant concentration of natural radionuclides owing to the presence of these same radionuclides in the raw material.

In recent years a detailed assessment has been made of a number of these activities and it is now possible to give an overview of the quantities, compositions and radioactivity levels of the wastes produced. This subject is covered further in Section 6.3 of this report.

2.2 Recent important developments affecting radioactive waste arisings

The enlargement of the European Union in 1995 added three new Member States. Of these, Finland and Sweden are nuclear power producing countries while Austria had decided in a pre-accession referendum to abandon nuclear energy as a means electricity production.

The total installed nuclear power production capacity in the EU is roughly 126 GWe. In France, limited light-water reactor capacity is being added, whereas in other Member States some nuclear capacity has been phased out. The most striking examples are the closure of eight Soviet designed reactors in the former German Democratic Republic, the abandoning, at the start-up phase, of a boiling-water reactor in Austria, and the moratorium on nuclear electricity production in Italy.

At the head-end of the nuclear fuel cycle the production of natural uranium in the Union territory is decreasing; uranium mines are closing down and subsequent environmental remediation measures are necessary. In Spain in 1994 the decommissioning of the Andujàr mill was completed as well as the rehabilitation of the tailing dykes; the closure and remediation activities at the East German mines operated by the WISMUT AG are also in progress.

Reprocessing of spent fuel, and vitrification of residual high-level waste, are now performed on an industrial scale in France and the United Kingdom, for both domestic and external customers. The resulting radioactive waste is returned to the customer and then stored in the country of origin.

Concerning fast-breeder reactors, those in the UK have been shut down and are being decommissioned, while the German SNR-300 reactor never started and the French PHENIX and SUPERPHENIX reactors have been used mainly for research purposes. A decision to shut down SUPERPHENIX definitively was taken by the French Government in July 1997.

With fast-breeder reactors no longer available as a sink for the plutonium and uranium produced from reprocessing, the fabrication of MOX (mixed oxide) fuel for light water reactors (LWR) has become the only way of recycling and using these materials. MOX production capacities in Belgium, France and the UK are large enough also to cover demand from utilities in

Germany where MOX production has been abandoned. Some countries have decided not to reprocess MOX fuel.

There is more awareness of the problem of natural radionuclides in concentrations enhanced by industrial processing. Activities such as management of tailings, sludges and scales, particularly in the phosphate and oil and gas industries, among others, may lead to significant radiological exposures of the population. The recently revised Basic Safety Standards (Directive 96/29/EURATOM) address this issue, but leave specific actions in the hands of the Member States following their own surveys and evaluations of the situation at national level.

2.3 Categories of radioactive waste used in this report

Radioactive waste comprises a large variety of materials of various physical and chemical forms that contain radioactive elements emitting various types of radiation[1]. Clearly, this diversity results in widely differing potential hazards and therefore necessitates different management schemes in order to ensure that safety criteria are met at all times. To simplify the management of radioactive waste on a large scale, radioactive wastes requiring similar treatment are grouped together into categories. This categorisation is not a regulatory requirement; rather the categories reflect the different treatment routes to which the various types waste can be subjected. Moreover, management practices vary from one country to another, which leads to the existence of a number of different categorisation schemes throughout the EU.

One common scheme, which has been used for the three previous reports in this series, distinguishes four main categories:

- low-level waste (LLW);
- medium- (or intermediate-) level waste (MLW);
- alpha waste;
- high-level waste from reprocessing, and spent fuel destined for direct disposal (HLW).

Here, the low, medium and high refer to the concentration of the radionuclides in the radioactive waste and hence to the intensity of the emitted radiation. This is a particularly useful categorisation for the general handling of radioactive waste and has been adopted in a number of EU countries, although the precise definitions of low, medium and high vary slightly.

Other countries use a categorisation scheme based on the lifetime and heat generation of the radioactive waste, and as such more directly related to the

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1 principally alpha, beta and gamma radiation

available options for final disposal. There is a growing consensus that recognises two main disposal options:

– surface or near-surface burial[1] for short-lived waste;

– deep geological repository for long-lived and heat-generating high-level radioactive wastes.

In 1994, the IAEA published a precisely defined categorisation scheme in which lifetime and heat generation were the principal criteria rather than activity concentrations. A similar scheme, based directly on disposal options and heat generation, has been adopted for the presentation of radioactive waste quantities in this report. The scheme comprises three categories:

- **LILW-surface** Low and Intermediate Level Waste destined to be disposed of, or already disposed of, or acceptable for disposal in surface or near-surface repositories. This is waste in which the radioactive content is sufficiently high for it to have to be managed as part of the national system of authorisation and registration, but for which the long-lived radionuclide content is within limits acceptable for surface or near-surface disposal.

- **LILW-deep** Low and Intermediate Level Waste destined to be disposed of, or already disposed of, in deep geological formations. This is radioactive waste which does not fall into the category of HLW, but in which the content of long-lived radionuclides is too great for disposal at or near the surface.

- **HLW/SFuDD** High Level Waste or Spent Fuel destined for Direct Disposal. This is waste in which heat generation must be taken into account, i.e. mainly vitrified waste resulting from the first extraction cycle of reprocessing operations, or spent fuel conditioned for direct disposal.

It should be emphasised that this categorisation scheme has been drawn up only for the purposes of this report as a way of presenting volumes of radioactive waste arising in each country acceptable for or destined for particular types of disposal. It is important to realise that the inclusion of a particular type of radioactive waste in one or another of these categories is country specific, since it depends on the management practices and policies in the country concerned and, in the case of an actual disposal facility, on the specific site characteristics. Germany, for instance, has decided to dispose of all types of radioactive waste in deep geological formations, and only distinguishes between non-heat-generating and heat-generating wastes. Consequently all types of waste, with the exception of HLW and spent fuel, are included in the 'LILW-deep' category.

1 Included in this option are the rock cavity repositories at depths of 50-100 m in Sweden and Finland.

Some countries have a category of 'very low-level' waste that is exempted from most of the regulatory controls applied to other radioactive wastes. This is discussed further in Section 4.3 (clearance levels).

Discharges of liquid and gaseous effluents into surface waters and the atmosphere take place subject to national and Community regulations. These discharges are regularly monitored and reported to the national regulatory authorities and to the European Commission. They form the subject of periodic Commission reporting and are not discussed further in this report.

2.4 Quantities of Radioactive Waste and Spent Fuel, and Facilities for Interim Storage and Disposal

The schematic diagram in Figure 2-1 shows the main management routes for radioactive waste, and includes letters indicating the corresponding tables of radioactive waste arisings and facility descriptions at the end of the report. Note that discharged spent fuel may take one of two routes depending on the national policy. Some countries have chosen to reprocess all or part of their spent fuel, others have opted for direct disposal following cooling and conditioning.

The production of radioactive waste associated with nuclear power programmes (including related research) is roughly proportional to the scale of those programmes (see Table A). However, it also depends on the type of reactors used[1] and the status of the nuclear installations (i.e. in operation, shut down, being dismantled). In addition, there is a general trend toward a reduction in volume of radioactive waste produced per kWh owing to the evolution of radioactive waste management technology and the impetus given by various schemes set up to finance radioactive waste management and disposal.

Radioactive waste produced before the end of 1994 is either:

- in interim storage (for the purposes of this report, interim storage encompasses all the stages between being produced and being disposed of, e.g. in store awaiting conditioning, undergoing some sort of treatment or conditioning, in conditioned form and awaiting final disposal); or
- has already been disposed of.

Interim storage: Some existing low- and intermediate-level waste is in interim storage (see Table B), either because no disposal facility has been provided until now in the country concerned, or because interim storage is the country's present policy, or because it represents a normal buffer in the management of existing disposal facilities. All high-level waste and spent fuel destined for direct disposal is in interim storage.

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1 As an example, the GGR (gas-graphite reactor) type, and its associated fuel cycle installations (reprocessing plants, etc.), still in use in the UK but no longer being developed, produces almost four times as much waste per kWh as the LWR type and associated fuel cycle installations.

Disposal: Some low- and intermediate-level waste (see Table C) has been disposed of in the past by:

- ocean disposal (practised by many countries up to 1982; in 1983 a moratorium was agreed within the framework of the London International Convention on the prevention of marine pollution, and is confirmed for a duration of 25 years);

- surface or near-surface disposal (Finland, France, Spain, Sweden, UK);

- deep disposal (Germany up to 1978 and from 1994).

No high-level waste or spent fuel has yet been disposed of in the European Union.

Estimates of future arisings of radioactive waste have been supplied by Member States and are presented as accumulated totals, over five-year periods, in Tables D, E and F for LILW-surface, LILW-deep and HLW/SFuDD respectively. The predicted evolution of radioactive waste arisings depends on a number of factors:

- the amount of electricity produced from nuclear power plants;

- the introduction of high burn-up fuel;

- how much waste volume reduction is assumed in anticipation of the gradual introduction of new treatment and conditioning techniques and of the optimisation of waste management at the sources of the waste;

- when the spent fuel is reprocessed and when the resulting radioactive waste is treated and conditioned;

- reductions in radioactive waste arisings through improvements in reactor modes of operation and fuel loading/unloading patterns, and through optimisation of fuel burn-up rates and strategies;

- when obsolete nuclear facilities are finally shut down and when the dismantling operations begin.

In supplying their data the Member States have taken into account the most likely national scenario for the above factors, though there are numerous reasons why these scenarios may change, leading in turn to significant changes in the estimates given in the tables. The evolution of a particular national nuclear power programme will be affected, in an uncertain manner, by future political decisions concerning the long-term share of nuclear energy in the national energy balance. In the UK, the privatisation of the electricity supply industry, including most of the nuclear power plants, adds a further level of uncertainty. In Sweden, the present national scenario involves a phasing out of nuclear energy by 2010, thus the radioactive waste arising after this time is assumed to be from decommissioning (tables D and

E) and from defuelling of the last reactor cores (tables F and G); clearly an earlier phase-out or an extended operation would affect these data.

However, the LILW waste arisings may rise sharply over the next decades from the decommissioning of obsolete nuclear facilities. The figures given in Tables D and E are based on the strategies currently under study in various Member States. Several national authorities find difficulty in making meaningful forecasts about the time schedule, and about the amounts of decommissioning waste, for the following reasons:

- the life of a power plant may be extended by up to a decade;
- national decommissioning policies have not yet been formulated; many nuclear power plants may be kept in a state of long-term care and maintenance at the end of their operating lives, and the resulting additional radioactive decay of the materials in the plant would allow for easier dismantling and a reduction in the quantities of waste arising, albeit at the expense of a longer period of institutional control;
- the amount of radioactive waste arising from the dismantling of a typical 1000 MWe nuclear power plant is estimated to be in the range 3,000 to 10,000 m^3, though the actual arisings at the time of dismantling may be different, depending on advances in decontamination techniques, possibilities for recycling, and on clearance criteria.

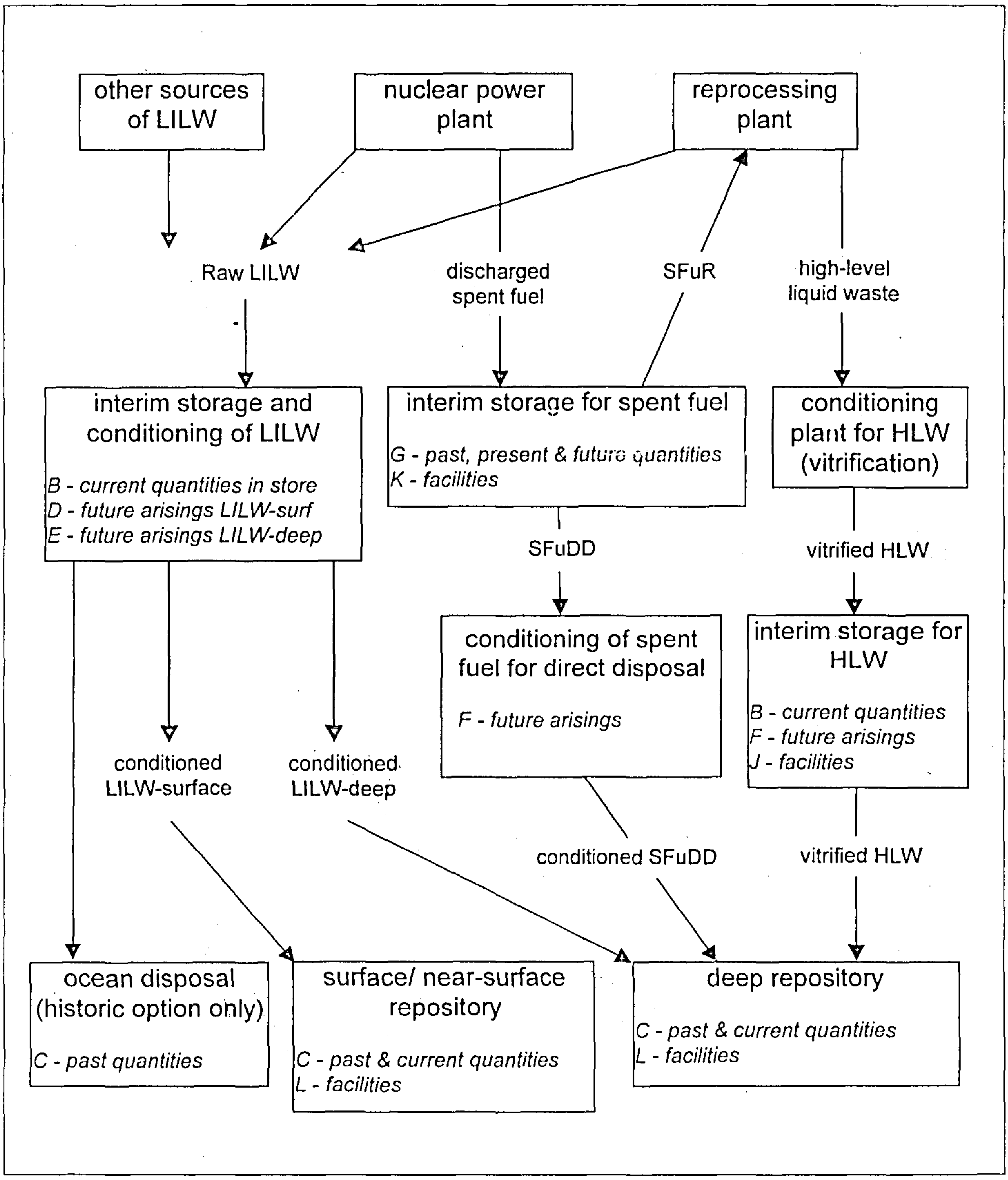
Table M provides a list of nuclear installations that have been definitively shut down, and indicates the status of the resulting decommissioning.

Most of the spent fuel from research reactors is in interim storage and amounts to a very limited quantity of highly enriched material. This fact, together with the large variety of possible fuel elements, means that reprocessing is difficult in large industrial facilities, although in the UK reprocessing of such fuel is still performed at the Dounreay site in Scotland.

Radioactive waste arising from the use of isotopes in industry, medicine and from general research is included in the inventories. All EU Member States produce this type of radioactive waste. Its production and future evolution is not governed by nuclear power programmes, but by the state of, and growth in, the industrial, economic and social development in the country concerned, as well as by size of and growth in the population.

Finally, it is important to realise that the cost and the design and research effort required to ensure safe storage and disposal of radioactive waste in a given national programme are relatively insensitive to the quantities of radioactive waste; future arisings will have little impact on the effort already envisaged.

Figure 2-1 Simplified flow diagram showing current and past main management routes for radioactive waste and materials giving rise to radioactive waste, indicating letter of corresponding Table A - L



SFuDD = Spent Fuel destined for Direct Disposal
SFuR = Spent Fuel destined for Reprocessing

3. POLICY AND PRACTICE OF RADIOACTIVE WASTE MANAGEMENT IN THE EU

3.1 Developments since the Third Report

The previous report described radioactive waste management as a set of co-ordinated steps from radioactive waste production to final disposal. Most steps in the classical scheme of sorting, treatment, conditioning, interim storage, transport and disposal have reached technical maturity. This has resulted in, amongst other effects, a reduction in discharges to the environment during the various stages of radioactive waste management. Since 1991, there has been considerable progress towards demonstrating that deep disposal of high-level heat-generating waste, which is the only aspect of radioactive waste management still to be realised, is both feasible and safe.

During the last five years the radioactive waste management situation in the European Union has been strongly influenced more by events of a political rather than scientific nature, the most important being the enlargement of the European Union.

As a consequence of the lack of orders for new power plants, the large industrial groups in this field in the EU have pooled their activities and developed instead their service sector. This has resulted in stronger competition in the repair and maintenance sector, which was formerly dominated by small and medium sized companies. This stronger competition is now even apparent in the radioactive waste management industry, where partly monopolistic structures exist.

At the world level, the adoption of the Convention on nuclear safety has been an important milestone in ensuring that a consistent standard of safety is guaranteed in nuclear installations throughout the world. Another important development concerns the Joint Convention on the safety of spent fuel management and the safety of radioactive waste management, which has been open for signature since September 1997.

More specifically in relation to radioactive waste, there is now a clear unwillingness on the part of policy-makers to allow waste from other countries to be stored and disposed of in their own country. Members of the public and environmental groups opposed to nuclear energy are objecting in particular to transport of nuclear material; in Germany, even railway tracks and equipment have been damaged in attempts to disrupt transport of spent fuel and vitrified waste to the Gorleben interim storage facility. Members of the European Parliament have asked for the application of the proximity principle in order to reduce transport. Transport difficulties have hindered the intended vitrification of liquid high-level waste, stored at the Karlsruhe WAK pilot reprocessing plant, in the PAMELA facility at Mol (Belgium). Since the chances of obtaining a license for transport of liquid HLW are slim, Germany now envisages the construction of a vitrification plant at the Karlsruhe facility itself.

The siting of disposal facilities has become a key problem. Few Member States have reported progress in site selection procedures; most have met stiff resistance from municipalities, regional representatives and the public, even concerning construction of underground laboratories required for research on deep disposal. There are, however, examples where underground laboratories have been sited and built in good co-operation with local municipalities.

The envisaged deregulating of the electricity market and utility privatisations will undoubtedly lead to more competition and cost cutting within this sector, and radioactive waste management will have to adapt to these new conditions. In particular, the practice of cross-subsidising the treatment and disposal of radioactive waste from small producers, compared with the somewhat higher charges for large producers, will be brought into question.

3.2 Radioactive waste management policy in the European Union

The Third Report described the national radioactive waste management system at Member State level to be made up of the radioactive waste producers, the executive bodies responsible for radioactive waste management, the regulatory bodies and the governments. In large nuclear power producing countries the Technical Support Organisations (TSO) must also be included, mainly as a support to regulatory bodies. Additionally, Union legislation and the Community Plan of Action provide a degree of harmonisation of policies, in particular through the Basic Safety Standards in radiation protection, especially regarding exposure limits and reporting levels. Table H summarises the organisations responsible for the various aspects of radioactive waste management in the different Member States.

3.2.1 Austria

Based on a 1971 legislative act, which specified that the safety authority will decide on the place to which radioactive waste is to be brought, the Austrian Research Centre Seibersdorf, in 1976, was the site designated for performing conditioning and storage of radioactive waste. At that time, construction of a 700 MWe boiling-water reactor (BWR) was in progress. The Research Centre also had the task of planning disposal of radioactive wastes, including that from the power plant, though the responsibility for managing this waste remained with the nuclear power plant owners.

In 1978 the power plant was ready for start-up, but a referendum on the use of nuclear fission for electricity production returned a majority opposing nuclear power. Following the referendum, the Ministry of Health and Environment took over the responsibility for siting a repository for radioactive waste from medicine, research and industrial applications. The Seibersdorf Centre provided treatment and conditioning services on a commercial basis to German utilities, the resulting treated and conditioned wastes being returned to the owner.

In a 1981-1984 study on repositories, an underground facility with 10,000 m^3 capacity was recommended, and 16 sites were proposed. Further studies allowed a reduction in the number of preferred sites to 4, and one of them, Bosruck-Süd, was selected for further investigation. As a result of strong opposition to implementing the repository, a policy of very long-term interim storage was finally adopted.

Austrian hospitals, industry etc. import sealed sources. Those spent sources that cannot be considered exempted from regulatory control are not returned to the supplier, but instead are stored at the Seibersdorf Centre.

The Austrian government is strictly opposed to permanent importation (with the exception of sealed sources) and exportation of radioactive waste, but accepts temporary imports for treatment and conditioning of radioactive waste from other countries. Consequently, there is no need for equivalence rules. Only a small percentage of the costs for interim storage and expected disposal of spent sealed sources are covered by the various users in research, medicine and industry.

3.2.2 Belgium

The country operates 7 nuclear power units at two sites with a capacity of 5.5 GWe, accounting for about 60% of electricity generated nationally. There are no plans for building additional plants.

The main radioactive waste arisings originate from:

- the nuclear power plants (radioactive waste from reactor operation);
- the reprocessing of spent fuel in France (vitrified high-level waste and conditioned non-heat-generating radioactive waste);
- the clean-up and dismantling of the former EUROCHEMIC reprocessing plant (including the PAMELA vitrification installations);
- the two fuel fabrication plants (FBFC and BN);
- the production and conditioning of radioisotopes in Fleurus;
- the operation of the nuclear research centres (CEN/SCK and CBNM);
- the clean-up at the former CEN/SCK Waste Department;
- the former radium production plant at Olen;
- small producers (spent sealed sources from medicine, research and industry).

About 70% of current arisings originate from the nuclear power plants. The plant operators have made enormous progress in reducing radioactive waste arisings at source in recent years.

Since its creation in 1980, the National Agency for Radioactive and Fissile Material, ONDRAF/NIRAS is the unique body entrusted with the management of radioactive waste of the country. Since then, the agency's responsibilities have been enlarged to cover management of 'foreign' nuclear waste and the dismantling of nuclear installations. This includes, in particular, the management of radioactive waste from the former EUROCHEMIC plant and the waste department of the research centre CEN/SCK, and has made it necessary to take over the Belgoprocess company. Furthermore, long-term solutions are being investigated, both economically and technically, for the materials left at the former radium production plant sited at Olen.

Indeed, a considerable proportion of expected arisings of radioactive waste comes from clean-up and dismantling of the defunct EUROCHEMIC installation and the Waste Department of CEN/SCK. There were no financial provisions for managing this material, or the waste from dismantling of the BR-3 reactor at Mol, and a fund has been set up by the Government and the utilities to cope with the financial consequences of this legacy.

According to the statutes of ONDRAF/NIRAS, at the demand of the producer or owner, radioactive waste in Belgium is collected by the agency at the producer's site. This radioactive waste is brought to the Belgoprocess site at Dessel; only the nuclear power stations Tihange and Doel perform partial treatment of radioactive waste from reactor operation in line with the agency's specifications. At the national site, radioactive waste is treated and conditioned, and stored awaiting disposal.

Belgium has disposed of all radioactive waste acceptable for sea disposal in the North Atlantic before the 1983 moratorium came into force.

There is still a backlog of radioactive wastes stored at Mol left over from the Transnuklear transactions. ONDRAF/NIRAS has made huge progress in getting rid of the backlog, treating some of the radioactive waste, and sending the remainder back to the owner.

After studying the options available, the construction of an on-surface engineered facility for disposal of short-lived radioactive waste, similar to the French Centre de l'Aube built on an impermeable clay layer, is favoured. In total, 98 suitable sites were identified, but the 47 municipalities in which they were located were all opposed to the construction of a repository on their territory. Concerning low-level waste, ONDRAF/NIRAS investigates, at the Government's demand, the different options from both safety and economics points of view.

For long-lived and heat-generating waste, studies are being carried out in the HADES Underground Research Facility (URF) situated in a clay layer at more than 200 m depth below the Mol nuclear site.

The nuclear power plants collect funds for decommissioning through a tariff on the unit electrical price. The expected cost of decommissioning the plants to a 'green field' state has been calculated by an independent consultant. The mean cost calculated for the seven nuclear power plants is covered by funds collected by the electricity producers by way of a kWh-tariff. In these calculations an operational life-time of 30 years and a 67% load-factor have been assumed.

Belgium imports a rather large number of sealed sources and is a also a producer of industrial radiography sources. Storage and disposal of spent sources is the task of ONDRAF/NIRAS.

Reprocessing of spent fuel was the normal option, but there is a moratorium on new reprocessing contracts so the discharged fuel is now stored at the nuclear power plant either in casks or in fuel ponds. Studies are being carried out on direct disposal of the spent fuel in clay.

3.2.3 Denmark

Risø National Laboratory, by agreement with the National Institute of Radioactive Hygiene, is responsible for collecting and storing radioactive waste from medicine, research and industry. The major part of the waste originates from the nuclear research facilities at Risø. Spent fuel from the research reactor is sent to the USA.

Spent sealed sources with more than trivial amounts of activity must be sent for storage at Risø or returned to the producer. To be accepted at Risø the spent sources or other types of radioactive waste must originate from work carried out in Denmark. When accepted for storage, the ownership and responsibility for the radioactive waste is taken over by Risø National Laboratory.

No disposal has so far taken place and no site selection studies have been carried out aimed at the disposal of the Risø waste. The chosen policy is to keep the waste in storage until complete decommissioning of the nuclear facilities at the research centre some time after 2020. Long-term management of the waste is considered a state responsibility.

3.2.4 Finland

Almost 30% of electricity is produced by four nuclear reactors, two 710 MWe BWRs at Olkiluoto, and two 445 MWe PWRs (VVER-440) at Loviisa.

In the case of Olkiluoto, TVO, the operating utility, has diversified its fresh fuel procurement by buying on the free market; spent fuel is stored in a pond type facility close to the reactor. The operator of the Loviisa plants, IVO, has arrangements with Russia for supply of fresh fuel. Spent fuel was returned to Russia up to the end of 1996. In 1994 the Finnish Parliament adopted an Amendment to the Nuclear Energy Act requiring domestic disposal of nuclear waste produced in Finland and prohibiting processing and disposal of foreign nuclear waste.

Radioactive waste from reactor operation is managed directly by the plant operators and disposed of in bedrock at the reactor sites at about 100m depth. The repository at Olkiluoto started operations in 1992. Construction of the repository at Loviisa was started in 1993; it will be operational in 1998. It is planned to dispose of radioactive waste from later dismantling of the power plants in extensions to these repositories. To manage the disposal of spent fuel, the waste agency Posiva Oy was created jointly by TVO and IVO, who hold 60% and 40% of shares respectively.

Spent fuel is to be conditioned in copper-iron canisters and disposed of in bedrock at a depth of several hundreds of meters. The site selection procedure has resulted in four candidate sites, among them the two NPP sites. At these sites landowners have agreed to allow detailed underground investigations. It is planned to select a final site in 2000, and construction could start in 2010.

Radioactive waste producers have full responsibility for managing their radioactive waste and for covering all related expenses. In order to cover expected expenses for radioactive waste management and decommissioning of the nuclear plants, TVO and IVO pay annual fees to a Government-controlled fund, which are tax exempted. Until the required amount is reached, the owner has to provide securities for the financial shortfall.

Finland imports all sealed sources used in the country; spent sources are either returned to the supplier or are managed by the Finnish Centre for Radiation and Nuclear Safety, which practices interim storage. Since 1997, this interim storage has been located in the premises of the Olkiluoto repository.

The need for arrangements regarding equivalence between wastes has not arisen.

3.2.5 France

France is the largest nuclear energy producer in the Union; EdF operates 54 PWRs (34 of the 900 MWe type and 20 of 1300 MWe) with a capacity of 58.6 GWe. Two fast-breeder reactors are operated mainly for research purposes, and a decision has been taken in July 1997 to close one of them definitively. The annual national electricity production from nuclear plants is around 350 TWh, which represents about 80% of the total French electricity production. Over the past few years, demand for electricity has been increasing at a rate of 2-3% per annum. Approximately 20% of the electricity generated in 1995 was exported.

All spent fuel is reprocessed at the plant at la Hague (operator COGEMA). The two facilities (UP2-800 and UP3) at the reprocessing plant offer an overall capacity of up to 1600 tonnes of spent fuel per year. Spent fuel from other EU countries, Switzerland and Japan is also processed at this plant. The recovered plutonium is recycled in the production of mixed-oxide (MOX) fuel at two other plants, the first located at Cadarache (Bouches-du-Rhône), and the second, the Melox plant, located at Marcoule (Gard). Fourteen of the 54 PWRs are currently using MOX fuel, and this is expected to rise to 28 units by the year 2005

The Agence Nationale pour la gestion des Déchets Radioactifs (ANDRA) was created by a interministerial decree in 1979 as an independent waste management agency within the French Atomic Energy Commission (CEA). The Waste Act of December 30th 1991 turned ANDRA into a state-owned establishment (EPIC) which reports to the ministries responsible for industry, environment and research. This act also defines ANDRA's duties and responsibilities for radioactive waste management.

To solve the problem of disposal of short-lived low- and medium-level waste, ANDRA designed and built two surface disposal facilities. The first, the Centre de la Manche, is adjacent to the La Hague reprocessing plant, and was opened in 1969. Its capacity of 526,000 m^3 was reached in June 1994 and it has since been closed. The Centre de la Manche is now entirely covered by a multi-layer engineered cap and is entering a period of institutional control that will last 300 years. The second, the Centre de l'Aube (250 km east of Paris), was designed in the mid-80s, and started operation in January 1992. This repository is designed to receive 1,000,000 m^3 of radioactive waste, which will normally cover the needs in France until 2040 at the earliest.

In the interest of optimising the management of short-lived low- and medium-level waste, both technologically and economically, ANDRA and the radioactive waste generators have jointly developed an integrated waste management system that covers all phases of waste processing, transportation and disposal.

In compliance with safety regulations, ANDRA developed technical specifications that require waste generators to submit, for ANDRA's approval, a waste acceptance file on each type of package they intend to produce. The second major component of the integrated waste management system involves tracking the waste from its production through to its final disposal. This is achieved using a computerised network linking the waste generators to ANDRA's headquarters, which enables the characteristics of each package to be recorded, compliance to be checked and shipments to be authorised, and packages to be tracked to their final destination.

Concerning long-lived medium-level waste and high-level waste, the Waste Act of December 30th 1991 established a clear-cut legislative framework and specified the research to be undertaken. The Act calls for studies to be conducted in three areas of research and sets a 15-year time limit. At that time, an overall assessment report on the research will be presented to Parliament, possibly together with draft legislation to licence the creation of a repository for high-level and long-lived radioactive waste.

The three areas of research are:

- *Separation and transmutation of long-lived radioactive isotopes in the waste*. Through exposing the waste radionuclides to an energetic particle flux, fission and capture reactions can be induced that result in reaction products of a shorter half-life and/or lower radiotoxicity. The so-called transmutation can only be applied to radionuclides and not to the waste, Therefore a preliminary chemical or physical separation (i.e. partitioning) step is necessary. The CEA is responsible for this research.

- *Evaluation of options for retrievable or non-retrievable disposal in deep geologic formations, in particular through the creation of underground laboratories.* This involves extensive studies to specify the sites' characteristics and to acquire geological and hydrogeological data on a large scale. To this end, shaft-sinking work should begin in 1998 and numerous experiments in the laboratories will continue until 2006. ANDRA is responsible for this second area of research.

- *Study of conditioning processes and long-term surface storage techniques for the waste.* This consists of studying waste packaging and waste storage options. The CEA is responsible for this third area.

These three research areas complement each other, and in 2006 an evaluation of the results should lead to a decision on the long-term management of radioactive waste.

In mid-1996, after two years of surveys of geological formations, licence applications for the construction and operation for three underground laboratories were presented to the authorities. During 1997, public enquiries, hearings and votes within the local populations were organised, and the results of this exercise appear positive. The Government's decision is expected during 1998.

The three sites investigated and proposed for hosting underground laboratories are:

- a clay site located at the border between the Meuse and Haute-Marne Departments;

- a clay site in the Gard Department;

- a granite site in the Vienne Department.

ANDRA is also actively involved in the question of very low-level wastes originating, for example, from uranium mining (i.e. tailings, residues), manufacturing processes using raw materials with a natural radionuclide content, or dismantling of nuclear plants. The intention is to establish a well-defined system for the management of the future arisings in this waste category that maintains the principles of waste producer responsibility and waste traceability.

3.2.6 Germany

The current nuclear reactor park, comprising light-water reactors only, has an installed capacity of 21.1 GWe (net), covering about 33% of electricity consumption. No new nuclear power plants are currently under construction.

The political situation dominates the policy of the back-end of the nuclear fuel cycle. The Federal Government favours the continued use of nuclear energy, but most regional governments are opposed to nuclear energy, and the largest opposition party, the Social Democratic Party, has included the termination of nuclear power production, the "Ausstieg", in its programme. Indeed, a number of important radioactive waste management installations are located in a Federal State (Land) whose Government is opposed to nuclear energy production. Attempts to overcome the deadlock by a 'consensus on energy' have failed.

Concerning uranium mining, the world's third largest producer of uranium was the Soviet-German WISMUT AG in East Germany. Nowadays, huge remediation activities are in progress, and a small amount of uranium is produced by in-situ leaching carried out to remove a maximum of toxic metals from already prepared ore body. German operators own shares in facilities for enrichment by centrifuge, e.g. URENCO Deutschland in Gronau, and the industry has abandoned fuel fabrication at Hanau, but still produces uranium fuel elements at Lingen and also in Richland (USA). The completion and operation of the MOX fuel fabrication plant at Hanau has been abandoned definitively; the plant's operation license had been blocked by the regional Government, despite the fact that all licensing requirements of the former Government had been fulfilled. MOX fuel for German facilities is now produced in other EU Member States.

Up to 1994, the spent fuel management policy was to reprocess all fuel with the exception of special fuel elements, which were stored until a disposal facility became available. As domestic reprocessing had been abandoned, reprocessing contracts were concluded with facilities at La Hague (F) and Sellafield (UK), and radioactive waste plus the plutonium and uranium are returned to Germany. Since 1994 a further amendment of the Atomic Energy Act (Atomgesetz) allows direct disposal of spent fuel, and as a consequence at least two reprocessing contracts have been cancelled by German utilities.

There are several 'away-from-reactor' (AFR) facilities for interim storage of containers of spent fuel, though vitrified waste from reprocessing can only be stored in the Gorleben interim storage facility. Spent MOX fuel will not be reprocessed, and a pilot conditioning facility for preparing spent fuel for direct disposal is under construction. The transport of containers with spent fuel and vitrified radioactive waste to Gorleben has run into heavy resistance by opponents and environmental groups.

Radioactive waste, as long as it is not treated by and stored at the nuclear power plant, is managed mainly by GNS (Gesellschaft für Nuklear Services); transport is entrusted, for example, to a subsidiary of the German Railways (NCS).

It is mandatory under German legislation to deliver the radioactive waste originating from small waste producers such as universities, industrial companies or hospitals, to regional collecting depots (Landessammelstellen). The procedure implicitly excludes foreign owners of waste from using these facilities and other interim storage facilities or repositories.

Experimental work on the disposal of radioactive waste was performed at the Asse salt mine until 1978, and is continuing at Morsleben, the former East German ERAM facility, which is also a salt mine. The Morsleben operational license is limited by legislation (on German unity) and will expire on 30th June 2000; the Bundesamt für Strahlenschutz (BfS) is legally responsible for the operation of this repository. The licensing procedure for the disposal of all types of non-heat-generating waste in the former iron-ore mine KONRAD is well advanced, and the underground exploration of the salt dome at Gorleben is continuing in order to provide proof of its suitability for disposal of all types of radioactive waste and spent fuel, in particular high-level waste.

German utilities have made provisions in their own accounts for decommissioning costs estimated at between 10 and 15% of new construction costs; most of the utilities have already accumulated the required amounts. Decommissioning of state-owned facilities, and in particular the construction of a vitrification facility for liquid high-level waste from the former operation of the WAK pilot reprocessing facility at Karlsruhe, has to be paid for mainly out of federal funds. Nevertheless, the utilities have made a considerable contribution to the financing of the WAK decommissioning activities.

Germany imports large numbers of sealed radiation sources, and is also a producer of such sources. Spent sources are either prepared for re-use or stored at the owner's site or at regional stores awaiting availability of disposal installations.

3.2.7 Greece

A 5 MW swimming pool type reactor is in operation at the National Research Centre "Demokritos". There is a local temporary storage facility for the spent fuel, pending exportation to the USA.

Provisions for the safe management of radioactive waste from medicine, industry, research and other applications of radioisotopes are included in the radiation protection regulations. An interim storage facility exists at "Demokritos".

A centralised storage facility for spent sealed sources is envisaged. At the moment the Greek AEC, the responsible authority, requires that spent sources be returned to the supplier.

3.2.8 Ireland

Radioactive waste from small producers using sealed and unsealed sources is stored at the producers' facilities in compliance with licence conditions set down by the Radiological Protection Institute of Ireland. Short-lived waste is allowed to decay before being disposed of as non-radioactive waste. Small amounts of long-lived waste may, under controlled conditions specified in the licence, be discharged to the environment

Sealed radioactive sources may only be imported if the supplier provides a written assurance that the sources will be taken back when no longer required by the licensee. Sources not covered by a take-back agreement must be stored indefinitely at the licensees' facilities.

A centralised facility is envisaged, primarily for the storage of spent sealed radioactive sources but also for small quantities of long-lived waste from nuclear medicine and research laboratories.

3.2.9 Italy

The referendum held in Italy in the wake of the Chernobyl accident revealed opposition to some of the existing nuclear legislation. The Government's interpretation was that all nuclear power production should be stopped, and as a consequence, the new National Energy Plan called for the closure and dismantling of all nuclear installations.

The different nuclear power plants are in stage 1 of decommissioning ('storage with surveillance', see Section 3.3.5). Some spent fuel is stored in the plant ponds and in an AFR ('away from reactor') pond at the former research reactor "Avogadro", and some has been sent to Sellafield (UK) for reprocessing, though it is still unclear if the remaining spent fuel will also be reprocessed. The residues from the reprocessing will be returned from the reprocessor.

Radioactive waste is stored at the producer's site; only the waste production resulting from medicine, industry and research is taken over by the radioactive waste management agency for conditioning and interim storage. Responsibilities for radioactive waste management are given to:

- ANPA (formerly ENEA/DISP) acting as the regulator;
- ENEA, responsible for decommissioning development, nuclear pilot plant and laboratory operator and major waste producer;
- ENEL, operator of nuclear power plants and major waste producer;
- NUCLECO, agency for collecting, treating and storing low- and intermediate-level waste resulting from the use of radioisotopes in medicine, industry and research.

The option of a centralised interim storage facility for spent fuel, vitrified waste and long-lived intermediate-level waste is under study.

Disposal of short-lived wastes on or near the surface is planned, and a list of possible sites has been transmitted to the Ministry of Industry. Deep disposal of long-lived waste in a clay formation is still under investigation.

As nuclear installations are state-owned, their decommissioning costs are financed from the general budget of ENEL and ENEA.

All sealed sources are imported, and spent sources are collected by NUCLECO at the ENEA site.

3.2.10 Luxembourg

The Radiation Protection Department from the Ministry of Health is responsible for licensing and supervision. All radioactive sources are imported, and spent sources, mainly from industry, must be returned to the supplier. Small quantities of short-lived waste are stored on the user's premises. As a non-nuclear country, Luxembourg does not currently operate a storage facility.

3.2.11 The Netherlands

From mid-1997 there has been only one nuclear power plant in operation in the Netherlands. The plant at Borssele is a PWR with an installed nuclear capacity of 500 MWe. It produces 3.5 TWh per year, which accounts for 5% of the total national electricity production. The nuclear power plant at Dodewaard stopped producing electricity in 1997. Furthermore, nuclear research reactors are operating at Delft and at Petten. Enrichment of uranium by the centrifuge process is carried out by Urenco (UK, NL and D owned) at the plant in Almelo.

All the spent fuel from the Dodewaard plant will be reprocessed by BNFL in the United Kingdom while that from the Borssele plant will be reprocessed by Cogema in France. The resulting reprocessing residues will be sent back to the Netherlands, starting in 2002.

The spent fuel from the research reactors was in the past returned to the USA, the country of origin of the fuel. In the future this spent fuel will be kept in the Netherlands and stored in the national waste storage facility.

The Netherlands policy on radioactive waste is based on the 1984 report on radioactive waste presented by the Dutch Government to Parliament in 1984. This report presented two fundamental orientations; firstly the long-term interim storage (100 years) of all radioactive wastes produced in the Netherlands, secondly the Government's policy on research into the possibilities of final disposal of such wastes. The former led to the establishment of the Central Organisation for Radioactive Waste (COVRA) at Borssele, whereas the latter led to the research programme on the disposal of radioactive waste.

The country imports sealed sources and also produces some types of sources; spent sources are sent to COVRA for storage.

The financing of conditioning, storage and final disposal of radioactive waste should conform to the principle that 'the polluter pays'. COVRA conducts its financial affairs in such a way that all costs are covered by the fees paid for the waste it receives. The fee covers all direct costs for transport, conditioning and storage, and also all financial provisions for the costs of future storage and eventual disposal. COVRA takes over full title of the waste, and the fees paid will not be adjusted retrospectively.

Funds for decommissioning of the nuclear power plants are collected by the operators via an internal scheme.

3.2.12 Portugal

The management of radioactive waste (small producers) is performed by Department of Radiological Protection and Safety (DPSR) of the General Directorate for the Environment.

All waste that cannot be disposed of, incinerated or left to decay where it is produced, is transported to the DPSR at Savacem, where a facility for treatment and interim storage of radioactive waste has been in operation since the 1960s.

All sealed sources are imported. Spent sources, when not shipped back to the supplier, are conditioned and stored at the DPSR site.

A 1 MW swimming pool reactor is operated by the Technology and Nuclear Institute. Spent fuel from this research reactor is stored in reactor facilities pending return to the USA.

3.2.13 Spain

The country operates nine nuclear power plants (7 PWR, 2 BWR) with a capacity of 7.5 GWe, or about 35% of the country's electricity production. Plans to build five additional plants were cancelled definitively by the Government in December 1994.

Uranium is produced near Salamanca; one uranium mill, Andujàr, has been decommissioned. A fuel fabrication plant is operating at Juzbado (province of Salamanca).

Reprocessing of spent fuel was limited to that from the Vandellos-1 gas-graphite reactor, which has been closed definitively and is currently being decommissioned; reprocessing residues will be returned from France for storage in Spain. All LWR fuel will be stored at the power plants (re-racking) and, if necessary, in metal containers. A central storage facility 'away from reactor' (AFR) is under consideration.

The radioactive waste management agency ENRESA collects, stores, and disposes of all types of radioactive waste. An on-surface repository, El Cabril, for short-lived waste has been operational since 1992. Plans for a deep repository have been drawn up, and clay, granite and salt formations are possible host rocks. A conceptual, non-site-specific preliminary design has been completed for the three host media.

To pay for back-end costs, including decommissioning of the power plants, ENRESA has set up a fund financed by a levy on the total revenue from the sale of electricity. This levy is revised annually, and the fund is exempt from tax.

In accordance with the Royal Decree authorising the setting up of ENRESA, the cost of the activities arising from management of radioactive waste is to be covered by those responsible for producing the waste. In the case of NPPs, a percentage charge is levied on the total revenue from electricity sales, while in the case of other waste producers payment is by way of tariffs charged at the moment of the removal of radioactive waste.

The country imports large numbers of sealed sources and has no domestic production. Spent sources are either returned to the supplier or may have to be collected by ENRESA.

3.2.14 Sweden

The country has an installed nuclear power capacity of 10 GWe with nine BWRs and three PWRs providing 50% of the country's electricity. After a referendum in 1980, the Parliament decided to phase out nuclear power by no later than the year 2010. How this can be achieved is now being discussed between the political parties in Sweden.

Most of the fuel elements for the Swedish reactors are fabricated in a plant at Västerås, which also exports part of its production. However, the uranium is imported, and all enrichment is carried out abroad.

All costs for the back-end of the fuel cycle, including decommissioning, are borne by the reactor operators via fees paid into state funds managed by the Swedish Nuclear Power Inspectorate.

The implementing waste agency, SKB, is owned by the nuclear utilities, and manages all types of radioactive wastes outside the power plants. The Swedish policy is deep geologic disposal of encapsulated spent nuclear fuel without reprocessing. Spent fuel is transported by ship to CLAB, the central underground storage facility at Oskarshamn, where an encapsulation facility is also planned. A central underground repository at approx. 50m depth for low- and intermediate-level waste, SFR near Forsmark, has been operational since 1988. The deep disposal of conditioned spent fuel is in a planning stage with ongoing R&D and siting studies. An underground facility, the Äspö Hard Rock Laboratory, is in operation, and contains experimental facilities down to repository depth. Since 1986, investigations, experiments and testing have been conducted in this facility as part of the national programme and in co-operation with nine foreign agencies. The site selection process, involving 5-10 site feasibility studies, is in progress. From these, two sites will be selected for site investigations. The application for a construction license is expected in 2003. The plan is to start with emplacement of only 10% of the conditioned spent fuel, and only to expand the capacity after a review.

Swaps of spent nuclear fuel have been made with Germany, based on an activity inventory equivalence.

Sweden imports the majority of its sealed sources; spent sources are registered and stored at the Studsvik Nuclear Research Centre. The final disposal can be either in SFR or the deep repository.

The Swedish Parliament has adopted a law forbidding permanent import of radioactive waste for disposal in Sweden.

3.2.15 United Kingdom

The United Kingdom currently operates 20 Magnox reactors, 14 AGRs and one PWR. Total capacity is 12.8 GWe, and the share of nuclear power in electricity production is of the order of 26% (in 1996). National nuclear power and radioactive waste management policies are defined by two Government reviews carried out in 1995.

The first review, into prospects for nuclear power in the United Kingdom, confirmed commitment to nuclear power provided it remained competitive and was able to maintain rigorous standards of safety and environmental protection. Equally, it was concluded that Government support for the building of new nuclear power units could not be justified against the background of current electricity markets.

The review also concluded that it would be beneficial to the industry, electricity consumers and taxpayers to move as much of the nuclear generating industry and associated liabilities as was practicable into the private sector. Accordingly, the more modern parts of the industry were subsequently transferred to two private companies, Nuclear Electric Ltd and Scottish Nuclear Ltd, which are themselves subsidiaries of a privately-owned holding company, British Energy plc. These organisations are now responsible for the operation of 14 AGRs and one PWR.

The older plants, including 12 operational Magnox reactors, several closed reactors and their associated liabilities were originally retained in the public sector under Magnox Electric plc. However, in early 1998 Magnox Electric was integrated into British Nuclear Fuels plc, the Government-owned reprocessing company, which operates eight Magnox reactors of its own.

United Kingdom radioactive waste management policy is set out in the Government's 1995 White Paper, "Review of Radioactive Waste Management Policy: Final Conclusions". The primary aim of the review, based on a national public consultation exercise, was to ensure that radioactive waste, irrespective of whether it was produced by public or private sector organisations, is safely managed in accordance with current international standards and guidance.

LLW is disposed of at the near-surface disposal facilities of BNFL at Drigg in Cumbria, and by the United Kingdom Atomic Energy Authority (UKAEA) at Dounreay in Caithness. Authorisations are also issued for the disposal of some LLW, mainly from outside the nuclear industry, by means of burial at suitable landfill sites.

UK Nirex Ltd, the company founded by the nuclear industry to develop a disposal route for ILW, had been concentrating its investigations on Sellafield as a potential site for a deep underground disposal facility for ILW and high alpha-content LLW. It has been conducting an extensive borehole drilling programme to test the geology and hydrogeology of the site. As part of its site investigation programme, it had applied for planning permission to construct a laboratory, known as the Rock Characterisation Facility, some 650m underground; this permission has not been granted.

HLW from the reprocessing of spent fuel is initially stored in liquid form in cooled, stainless steel tanks. BNFL is in the process of converting the liquid waste into glass cylinders to make it safer and easier to manage. The vitrified waste is then stored for at least fifty years in order for the short-lived radionuclides to decay and heat generation to reduce. The Government's favoured option for the long term, as stated in the White Paper, is for the disposal of HLW in geological formations on land, once it has been allowed to cool.

Within the UK, the producers and owners of the radioactive waste are responsible for bearing the cost of its management and disposal, including regulatory costs. This includes the cost of spent nuclear fuel storage and disposal of waste from reprocessing. Provision is made in accounts to meet these liabilities.

Other notable United Kingdom nuclear operations are MOX fuel fabrication at Sellafield, uranium enrichment at Capenhurst, and conversion at Springfield and Windscale.

The UK is a large producer of sealed sources and, as a large exporter, receives a substantial quantity of spent sources from their customers either for recycling or storage prior to disposal.

3.2.16 European Commission

The Commission owns an operating test reactor (HFR Petten) and closed test reactors at Ispra (Italy), and operates nuclear installations at Ispra (Italy), Petten (Netherlands), Karlsruhe (Germany) and Geel (Belgium). Radioactive waste produced at these Joint Research Centre sites is managed within the system of the host country. Studies on decommissioning of the reactors at Ispra started in 1997.

Community legislation is of paramount importance in nuclear safeguards, in the ownership of nuclear material, and throughout the common nuclear market. Member States are required to implement, in the nuclear sector, directives on basic standards of radiation protection, control of shipment of radioactive material, and performing of an environmental impact assessment for new facilities, which includes public information activities.

Co-operation between Member States and the Commission is established in the framework of the "Community Plan of Action in the Field of Radioactive Waste Management", which has been renewed until the end of 1999.

A "Strategy for Radioactive Waste Management" has been adopted by the Commission in 1994, which spells out a number of actions to be accomplished. Progress has been made on: the assessment of risk from waste containing natural radionuclides in concentrations enhanced by industrial processing; the development of the principles for harmonisation of categories with a view to disposal, on radioactive waste equivalence; the promotion of dialogue between radioactive waste agencies and safety authorities with regard to the safety case for a deep underground repository.

An important line of Commission policy is to favour an approach to radioactive waste management in the common nuclear market that promotes the unrestricted movements of goods, workers and services between Member States. In particular, the Commission favours co-operation between Member States leading to a reduction in the number of facilities. In 1996, with reference to the above approach, the Commission stated that they were "of the opinion that this practice should also be pursued in the future"[1].

3.3 Current practice

3.3.1 System approach

Ideally, radioactive waste is managed through a complete system involving collection, sorting and pre-treatment, treatment to produce a stable waste form, conditioning and disposal, with intervening steps covering storage and transport. The different elements of the system are closely inter-related, and if any one is missing then there may be a knock-on effect elsewhere.

Management systems may be complex owing to the nature of the waste, the geographic location of waste procedures and as a consequence of national policy. The EU Member States operate various management schemes, each dealing with the different radioactive waste types in accordance with national policy and practice.

Owing to their large volume, the tailings from uranium mining and milling are necessarily managed on and around the site. Remediation and decommissioning involve, in particular, protection against contamination of groundwater and surface water and construction of covers to limit radon emanation.

In the case of short-lived waste (i.e. about 30 years half-life) containing a strictly limited amount of long-lived nuclides, four Member States (France, Spain, Sweden and United Kingdom) operate surface or near-surface disposal facilities. As such, these countries have a complete management

1 extract from response to oral parliamentary question N° H-0723/96

system for this type of waste. Other countries, e.g. Belgium, envisage establishing a similar system.

Some Member States have taken the decision to dispose of the bulk of radioactive waste underground, either at low depth (up to 100 m) or much deeper. This is already practised for non-heat-generating waste in Finland, Sweden and Germany. No high-level waste has yet been disposed of in Member States, but all countries with such waste plan to realise deep underground disposal, and some are currently operating underground laboratories. In the meantime, HLW and spent fuel declared as being waste are safely stored in surface facilities.

Radioactive wastes resulting from the use of radionuclides in medicine, industry and research are either stored at the user's premises, or sent to a regional or national storage facility. The practice of returning spent sealed sources to the initial supplier for treatment and re-use is becoming more widespread.

Some Member States have decided to postpone decisions on HLW, or on all types of waste, for periods of from 30 to 100 years.

3.3.2 Treatment and conditioning

The processes and techniques for treatment and conditioning for LLW and ILW are well established. Liquid radioactive waste is treated mainly by evaporation, ion-exchange and chemical precipitations with filtration in the case of aqueous wastes. For solid waste, compaction or supercompaction, melting (for metals) and incineration are commonly employed.

Conditioning creates a stable solid waste form, thus making the final package suitable for interim storage and/or disposal. Depending on the requirements for the package, waste, e.g. ingots from metal-melting or compacted ashes, is enclosed in containers and included in a matrix of mainly cement-based material; bitumens and polymers are also added as an immobilisation material.

Processes and techniques have been explained in previous reports. In the present report, only important new installations that have become operational since 1992, together with the main installations in the new Member States, will be mentioned.

In Belgium, the CILVA facility for centralised treatment and conditioning of those radioactive wastes not already treated at the power plants was completed and became operational towards the end of 1995. It comprises a 1500 tonne supercompactor and an incinerator of 100 kg/h throughput; the incinerator is not designed to treat alpha-waste.

In the Netherlands, a similar treatment facility for low- and medium-level radioactive waste has been installed by COVRA. This centralised facility was built between 1990 and 1992, and the treatment installations became operational in 1993. The following separate installations are presently available:

- super compactor (1500 ton);
- separator for organic/inorganic liquids;
- dedicated incinerator for biological wastes;
- dedicated incinerator for organic liquids;
- shearing and cutting installations;
- cementation station;
- waste water treatment system.

In France, a smelter for contaminated metal, specifically for material from decommissioning of the G-3 reactor, has started operation at the Valrhô Centre at Marcoule. Also at Valrhô, the smelter for spent fuel hulls has been commissioned and is being operated with active material.

In Spain, the waste from small producers is treated at the El Cabril facility (incineration, compaction, immobilisation), which is also where the compactable wastes from NPPs are supercompacted; all wastes are conditioned in a standard concrete container prior to disposal at the facility.

In the United Kingdom, the Enhanced Actinide Removal Plant (EARP) for the treatment of low and medium-level liquid wastes produced at Sellafield has become operational.

The new Member States also have appropriate treatment and conditioning facilities:

- Austria operates, at Seibersdorf, plants for liquid radioactive waste treatment, a compactor and an incinerator.

- In Finland, the power plant operators treat and condition all waste at the reactor site. Incineration is not practised. Olkiluoto uses bitumenisation for spent resins; there is no solidification facility for liquid radioactive wastes at Loviisa and these are currently stored untreated in tanks.

- In Sweden, most of the reactor waste is treated and conditioned on-site, but at Studsvik there is a central facility for incineration of combustible waste and a smelter for contaminated metal.

For high-level waste from reprocessing, vitrification is performed routinely at La Hague (France) and at Sellafield (United Kingdom). In Belgium, the PAMELA ceramic smelter has been used to vitrify EUROCHEMIC waste. Conditioning of spent fuel (encapsulation) is not yet practised on an industrial scale. A pilot conditioning plant is nearing completion in Germany, and in Sweden a pilot plant for testing industrial scale encapsulation of spent fuel is under construction

3.3.3 Interim storage facilities

At various stages in the 'life' of radioactive waste it will be held in interim storage awaiting some form of conditioning or final disposal. An update is given below of interim storage facilities in the different Member States. These facilities may be at or near the producer's site, located regionally or at a centralised location in the Member State.

3.3.3.1 Low- and intermediate-level waste

For this type of radioactive waste from all sources, centralised storage is practised in Austria, Belgium, Denmark, Germany, Portugal, The Netherlands and Greece. In Ireland, Luxemburg and Finland, waste is stored at the producer's site.

France has buffer stores for short-lived waste waiting for disposal at the Centre de l'Aube. Long-lived waste is stored regionally, principally at Marcoule, La Hague and Cadarache.

In Finland, only 'at-reactor' (AR) interim storage for radioactive waste awaiting treatment prior to disposal is needed. A central storage exists for small producers' waste.

In addition to central storage facilities, Germany operates a number of regional storage facilities (Landessammelstellen) for the radioactive waste originating from small waste producers. Nuclear power plants, nuclear research establishments and the other nuclear fuel cycle facilities all store conditioned radioactive waste on their premises. The ERAM (Morsleben) disposal facility will also accept suitable radioactive waste, up to the anticipated authorised capacity for this type of waste.

In Italy, radioactive waste from nuclear power plants is stored at the point of production; a large proportion is stored untreated. Radioactive waste outside the nuclear fuel cycle is collected for central interim storage by NUCLECO.

Spain has buffer stores for short-lived radioactive waste awaiting disposal at the El Cabril centre. There is also storage capacity for LILW at each NPP.

In Sweden there is local storage capacity for LILW waste at each nuclear site. Radioactive wastes from other locations are collected for centralised interim storage at Studsvik. These facilities provide buffer storage before transport of the waste to the operating disposal facility SFR, situated close to Forsmark.

In the United Kingdom, radioactive waste not acceptable for disposal at Drigg and Dounreay is generally stored at the producer's premises. Conditioned ILW is now being stockpiled at Sellafield awaiting a Nirex repository.

3.3.3.2 High-level waste from reprocessing and spent fuel destined for direct disposal

Vitrified high-level waste from reprocessing is currently held in interim storage awaiting final disposal; a summary of the actual and planned facilities are shown in Table J. Spent fuel storage facilities are shown in Table K, and include those for spent fuel awaiting conditioning prior to direct disposal and those for spent fuel awaiting reprocessing. In addition to the facilities in Table K, in some Member States a relatively small number of special fuel elements, such as those from research reactors and material test reactors, are normally held on-site awaiting return to the producer.

Belgium has completed a storage building for vitrified high-level waste on the site of Belgoprocess at Dessel.

In Finland, spent fuel of the Olkiluoto plant is stored in ponds near the power plant. Until the end of 1996, the Loviisa plant sent spent fuel back to the Russian Federation. After this, spent fuel is stored in the reactor ponds and in an additional storage building that will be enlarged within the next few years.

In France, vitrified waste is stored at La Hague and Marcoule, and special spent fuel is stored at Cadarache; huge ponds at La Hague allow for interim storage of spent fuel awaiting reprocessing.

In Germany, spent fuel not intended for reprocessing and vitrified waste is and will be stored mainly in central storage facilities; the storage is in casks that are also licensed for transport. The Gorleben storage facility is licensed for casks containing spent fuel, spent MOX fuel, vitrified HLW from reprocessing, and internally contaminated empty containers; the first emplacements took place in 1995 and 1996. In 1995, the Ahaus storage facility received 305 containers with spent fuel from the THTR plant; an extension of the license to allow storage of spent light-water reactor (LWR) fuel and research reactor fuel was submitted to the licensing authorities in September 1995. The license would allow storage of up to 4200 tU with a maximum of 2 x 10^{20} Bq and 17 MW decay-heat. At the container storage facility located in the Jülich Research Centre, 90 casks with spent AVR fuel, out of a maximum of 158 permitted by the license, have been emplaced. In addition, a license application has been submitted to permit storage of spent research reactor fuel of the GLE-1 type.

The interim pond storage facility ZAB Greifswald contains about 4500 fuel elements of the VVER type, which is close to the maximum capacity of 4680 elements. A request for a modified license has been submitted for the container storage facility ZLN Rubenow, which would permit storage of spent fuel from the former GDR reactors at Greifswald and Rheinsberg, and of elements from the ZAB facility up to a maximum of 620 tU, 5 x 10^{19} Bq activity and 1 MW decay heat.

In Italy, no NPPs are now in operation. Spent fuel from Latina has been sent abroad for reprocessing, and the vitrified waste is expected to be returned in some years' time. In the case of the NPPs at Trino, Garigliano and Caorso, reprocessing contracts exist for some of the spent fuel, and a part has already been sent abroad in the case of Trino and Garigliano.

The remaining fuel is stored at the reactor (concerns Caorso and, partly, Trino) or has been transferred to the pond of the former research reactor "Avogadro". Some spent fuel from Trino and the MTR-type research reactor elements are stored in the storage pond of the EUREX pilot reprocessing plant. The storage pond of the ITREC pilot reprocessing plant still holds 64 U-Th spent fuel elements from the U.S. Elk River Reactor.

In the Netherlands, the policy is to send the spent fuel of the nuclear power plants abroad for reprocessing. However, spent fuel from the research reactors will remain in storage. To facilitate the handling and storage of this spent fuel and vitrified reprocessing waste, the construction of a naturally cooled storage vault is planned. Construction will start in 1998 and the first shipment of conditioned high-level waste from reprocessing is scheduled to take place in the year 2002.

Spain has a policy of expanding storage capacities at the NPPs. Nevertheless, plans are in progress for a centralised store able to receive vitrified waste returning after the reprocessing in France of fuel from the gas-graphite reactor Vandellos-I, and spent fuel from the light-water reactors.

Since 1985, Sweden has operated a centralised underground pond storage facility, CLAB, where the spent fuel will be stored for a period of 30 to 40 years. The present storage capacity of 5000 tonne of heavy metal will be expanded to 8000 tonne. There are plans to construct a fuel encapsulation plant in an extension to the CLAB facility at the end of the century.

In the United Kingdom, reprocessing of spent fuel has been the only management route to date (although there are some anticipated arisings of spent fuel for which reprocessing contracts have not yet been signed). Fuel is stored in ponds, and vitrified HLW is planned to be stored for at least 50 years at a new dry storage facility located at Sellafield.

3.3.4 Disposal

All Member States study disposal options, and an appreciable number of facilities are operating. Ocean disposal is subject to a 25-year moratorium and is currently not practised. A summary of current and planned disposal facilities is shown in Table L.

Belgium is continuing geological disposal research at the HADES Underground Laboratory (clay formation) at Mol. The siting process for an on-surface engineered disposal facility is in progress.

In Finland, reactor waste from the Olkiluoto plant has been emplaced since 1992 in an on-site repository at 100 m depth in granite. Construction of a similar facility at the Loviisa NPP site was completed in early 1997. Site selection procedures are underway for a deep repository for encapsulated spent fuel in bedrock, which, it is expected, will be completed by 2020.

France is in the process of moving to period of institutional control at the Centre de la Manche repository, which has received 526,000 m^3 of radioactive waste suitable for on-surface disposal. This type of radioactive waste is now placed in the facility at Centre de l'Aube, which has a 1,000,000 m^3 capacity. The siting procedure for building underground laboratories narrowed the possible sites to clay formations in the Gard, Haute-Marne and Meuse regions, and a granite formation in the Vienne region. It is possible that three underground laboratories will be excavated.

Germany operates the ERAM facility in a salt dome in Morsleben, Sachsen-Anhalt, as a repository for short-lived low- and intermediate-level radioactive waste with low alpha-emitter concentrations. The former Konrad iron-ore mine in Lower Saxony is about to obtain the license for disposal of all types of non-heat-generating waste. The salt dome at Gorleben (Lower Saxony) is under scrutiny for its suitability as a disposal site for all types of radioactive waste, in particular heat-generating waste (HLW and spent fuel). Two shafts have been sunk to more than 800 m and the excavation of horizontal galleries has started in order to investigate the salt dome interior.

In Spain, the near-surface repository at El Cabril, which has engineered barriers for short-lived low- and intermediate-level waste, started receiving waste in November 1992. In the case of high-level waste, a siting procedure aimed at drawing up a 'National Inventory of Favourable Formations', as well as identifying areas potentially suitable for hosting a deep geological repository, has been in progress since 1986. The next steps will be oriented towards, on the one hand, defining the necessary legal framework, and, on the other hand, assisting the public debate over site selection.

In Sweden, the underground repository for radioactive waste from reactor operations, SFR located near the Forsmark NPP, was commissioned in 1988. The rock caverns have been excavated at a depth of 50 m below the bed of the Baltic Sea, with access from land, and have capacity of 60,000 m^3. The siting process for a repository in bedrock for encapsulated spent fuel is well advanced, and the first emplacements are planned for 2008 at the earliest.

In the United Kingdom, radioactive waste with less than 4 GBq/ton alpha and 12 GBq/ton beta-gamma activity continues to be disposed of by shallow burial at Drigg and Dounreay.

3.3.5 Management of radioactive waste from decommissioning

Decommissioning policy more or less follows the three-stage internationally accepted IAEA approach:

- **Stage 1 - Storage with surveillance**
  During this stage the preliminary decommissioning activities are carried

out. Both during and subsequent to this stage continued surveillance of the reactor is necessary.

- **Stage 2 - Restricted site use**
  During this stage further decommissioning activities are undertaken, though without complete dismantling of the reactor. Remaining parts of the reactor and site facilities should be subject to a further period of storage with surveillance.

- **Stage 3 - Unrestricted site use**
  During this stage, decommissioning of the reactor is completed, leading to the release of the site for unrestricted use.

Delaying the decommissioning allows the strong short-lived gamma-emitting radionuclides to decay significantly, thus facilitating later dismantling. In addition, in those countries where no repositories for decommissioning waste exist, complete dismantling may not be a cost-effective approach.

Most Member States have adopted the strategy involving some form of storage with surveillance, and are delaying dismantling for between 30 and 100 years. One such example is the 'safestore' concept proposed in the UK. However, considerable experience has been gained from demonstration dismantling operations carried out on certain facilities, which confirms that safe dismantling is feasible and can be achieved at reasonable cost.

Table M provides a list of installations at various stages of decommissioning in the European Union.

One of the important considerations in decommissioning operations is clearance levels for release of very low-level active material from regulatory control (see Section 4.3); procedures for restricted and unrestricted release have been studied extensively at national and international level.

3.4 Future developments

A large body of information on treatment, conditioning, storage and disposal of all types of radioactive waste is available, and the feasibility and safety of waste management procedures and processes have been widely demonstrated. In particular, disposal of short-lived and low-level radioactive waste with a restricted content of long-lived radionuclides is practised by countries with advanced nuclear programmes.

There are continuing activities aimed at the minimising of waste quantities, improvement in waste forms and engineered barriers, and development of quality assurance procedures for the products and processes. Nevertheless, as many countries are now going through a site selection procedure for deep geological disposal of high-level and long-lived waste, performance assessments and associated areas of investigation have become the priority activities in research and development. As an alternative management possibility, partitioning and transmutation for some particular radioactive waste streams have attracted considerable interest (and funding) in some Member States (France, the Netherlands and, to some extent, Germany), and are receiving new interest from others.

Decommissioning of nuclear installations, with the exception of the dismantling of large reactor pressure vessels, has now been well tested, including by full-scale demonstrations. Improvements in dismantling techniques and optimisation of management routes for some waste streams are still being sought. Criteria for exemption and clearance of very low-level waste have been proposed, and the recycling of waste from dismantling within and outside the nuclear sector is being studied.

A significant part of the research and development (R&D) in the radioactive waste and decommissioning area is integrated in the Communities' shared-cost programmes. For this reason the main activities of these R&D programmes performed since the publication of the previous report will first be summarised in Sections 3.4.1 and 3.4.2. These are followed in 3.4.3 by a summary of the European Community's Joint Research Centre (JRC) R&D programme, and in 3.4.4 by brief outlines of the programmes in the individual Member States.

3.4.1 The European Commission's R&D programme on nuclear fission safety

Within the 1994-1998 shared-cost programme, waste management is considered as an overall system, in which topics are grouped under:

- radioactive waste (reduction of arisings and releases, qualification of engineered barriers);
- disposal (demonstration of feasibility of deep disposal, long-term safety);
- system as a whole (quality assurance and control).

Most of the work is devoted to the further development and consolidation of the safety assessment methodology, as well as to its application on different sites, concepts and waste inventories.

This safety assessment methodology is applied to the following main programme tasks:

- performance analysis of repositories containing spent fuel;
- safety aspects of repository concepts designed for retrievability.

Research to improve the input database and associated models includes:

- experimental research and modelling of the source term for spent fuel and HLW glass, barrier performance of canister and backfill;

- development, from experimental investigations, of models for thermo-hydromechanical and geochemical properties of certain engineered barrier materials and near-field host rock;

- refinement of radionuclide migration models by taking into account organic complexing agents and colloidal species as well as by modelling the chemical thermodynamics and possibly kinetics of radionuclide transport;

- quantification of significant retardation processes (sorption, chemical interaction) for radionuclide transport through porous and fractured rocks.

Investigations are being made to test and validate radionuclide migration models on natural analogues (e.g. the well-known Oklo natural reactor in Gabon). The study of these natural phenomena can provide a valuable understanding of migration processes over millions of years, such as:

- investigation of the long-term stability of the near-field chemical environment;

- studies of radionuclide release and transport processes observed in natural systems.

Investigations into possible variations in the natural evolution of sites involve:

- research on past geological events (uplift, subsidence, erosion);

- investigation of climatically and tectonically induced changes in groundwater flow.

The programme supports the operation of research facilities in clay (HADES, Mol (B) and Tournemire (F)), in salt (Asse (D)) and in crystalline rock (Grimsel (CH)). This research aims at establishing the feasibility of disposal concepts and at providing data on the long-term behaviour of various components of these multi-barrier disposal concepts.

A further common activity is the "European Network of Testing Facilities for the Quality Checking of Radioactive Waste Packages". The network includes twelve laboratories that co-operate in the development, application and standardisation of quality checking for radioactive waste packages.

Studies exploring new fuel cycle concepts are in progress and involve strategy studies, and partitioning and transmutation techniques. Strategy studies include:

- the evaluation of possible partitioning and transmutation strategies;

- providing nuclear data for advanced MOX fuels;

- thorium fuel cycles aimed at reducing waste arisings and waste 'burning';
- the impact of accelerator based technologies on safety of the nuclear fuel cycle.

Concerning partitioning and transmutation, certain funding within the 1994-1998 programme is devoted to the development of advanced techniques applicable to long-lived radionuclides. The main objective is a reduction of the plutonium inventory, though a reduction in the americium inventory is also important since this is a major contributor, through neptunium in-growth, to the very long-term doses from an underground repository. However, before it can be destroyed (i.e. by transmutation), a chemical separation, or partitioning, process has to be developed to extract americium from liquid waste without generating large quantities of secondary waste. Some very long-lived fission products, for example technetium-99 and iodine-129, are also candidates for transmutation. Two experimental projects are aimed at improving transmutation techniques, and involve irradiating an americium target in a high thermal flux, and a technetium-99 target with a neutron spallation source driven by a proton synchrotron.

R&D on radioactive waste management will continue as part of the 5th Framework Programme starting in 1999. A proposal for a Council Decision on the 5th Programme has been established in mid-1997.

3.4.2 The European Commission's R & D activities on decommissioning of nuclear installations

The dedicated decommissioning R&D programme has formally come to an end in December 1993, but some of its activities are continuing under the current nuclear fission safety programme.

The activities in the programme were devoted to:

- R&D on decommissioning technology, including long-term integrity of buildings and systems;
- development of guiding principles aimed at reduction of exposure and confinement of radioactivity;
- testing and demonstration of decommissioning techniques in full-scale dismantling (four pilot dismantling projects).

In most areas of decommissioning the industrial application stage has been reached. For this reason, Euratom research is now concentrating on the following activities:

- the development of innovative dismantling techniques (certain projects are supported in particular with a view to the testing of decommissioning strategies mainly addressing the dismantling of reactor pressure vessels and core internals; a large part of the work is carried out at the pilot projects at BR3 (B), KRB-A (D) and WAGR (UK), and in Greifswald(D));

- the collection of technical performance data (data concerning the performance and environmental effects of dismantling techniques at decommissioning projects in Europe are stored in the EC-DB-TOOL database);
- the collection of data on specific waste arisings, doses and associated costs (this involves the maintenance and further development of an existing database).

3.4.3 The European Community Direct R&D Action programme implemented by the Joint Research Centre

The optimisation of waste management and the minimisation of waste radiotoxicity imply basic research on actinides and transuranium elements. This is an area where the Joint Research Centre of the European Community has developed unique expertise within Europe. It is thus the focal point of several European collaborative networks. These R&D activities cover two main areas:

- *Transmutation studies aimed at minimising the concentrations of long-lived nuclides in radioactive waste.* These studies concentrate on:
  - the development and testing of fuels containing technetium and minor actinides (Np, Am, Cm);
  - advanced techniques for the handling of these materials during fabrication and reprocessing;
  - investigations on possibilities of recovering these nuclides after reprocessing.

  With the view to an optimisation of waste management practices, the results of these studies will be used for a critical comparison of various fuel cycle options: once-through LWR fuel cycle; self-generated Pu recycle with and without minor actinides and technetium; fast-reactor fuel cycle with minor actinide and technetium recycle.

  These activities also contribute to network collaboration with the participation of laboratories in France, Germany and the Netherlands, in particular **EFTTRA** (Experimental Feasibility of Targets for **TRA**nsmutation) on partitioning and transmutation.

  In order to reduce the build-up of minor actinides, so-called 'inert matrices', such as spinel ($MgAl_2O_4$), MgO, Al_2O_3, $ZrSiO_4$ etc., are tested. For long-term reactor operation and storage of such matrices, their radiation stability and thus their response to radiation damage due to alpha decay (self-damage) and due to reactor irradiation (fission damage) are studied.

Furthermore, a new attempt is being made to establish a radiotoxicity 'ranking' of nuclear waste constituents, taking into account realistic environmental conditions and the most recent assessment of the biological effects of various nuclides. In particular, the possibility of replacing ^{238}U in nuclear fuel by inert matrix materials in order to reduce the production of long-lived transuranium elements during reactor operation will be further explored, and the evolution of the radiotoxicity of these alternative fuels will be investigated.

- *The characterisation of unprocessed spent fuel.* Work in this area includes:

  - development and testing of instruments and methods in order to determine the nuclide composition and to compare experimental findings with theoretical predictions;

  - research on the mechanisms and the kinetics of leaching, using synthetic fuel forms, with solid state physical methods, in parallel with studies on 'real' samples exposed to conditions which may prevail in an intermediate or a final repository;

  - development and testing of mathematical models describing the behaviour of spent fuel under long-term storage conditions;

  - evaluation of the radiotoxicity of classical and alternate waste forms and its evolution with storage time.

3.4.4 R&D in the Member States

Austria is studying the long-term suitability of surface disposal facilities for all the types of waste produced and stored in the country.

Belgium is continuing research on improved waste (possibly including spent fuel) processing and packaging techniques. Site selection and design of a surface disposal facility, together with environmental impact studies, are also performed. The most important share of research is devoted to the work in the HADES underground clay laboratory.

In Denmark, barrier properties and waste product characteristics are studied with emphasis on near-surface disposal.

In Finland, the major waste producers are obliged by legislation to carry out research and development work for the safe management of their wastes. The annual cost of the industry's R&D programme is about 8 MECU, and is concentrated on the final disposal of spent nuclear fuel. The R&D work is performed in close co-operation with Sweden and other countries investigating final disposal of spent fuel or HLW in crystalline rock. There is also a publicly funded R&D programme to support the regulators in their tasks related to waste management. The financing for this programme is about 15% of that of the industry's programme.

France pursues research activities in compliance with the Act of 30/12/1991; these activities are described in detail in Section 3.2.5. Another important area of research is that devoted to natural analogues, particularly studies on the natural nuclear reactor at Oklo (Gabon). Decommissioning is already performed on an industrial scale, and research in this area is limited to management of very low-level waste.

In Germany, government-supported research is limited essentially to direct disposal of spent fuel. Research related to future disposal facilities and their safety are carried out on behalf of the Ministry for Research and the Ministry for Environment, but costs are mainly taken over by the large waste producers. The Ministry for Research also supports basic R&D on safety technology and tools for safety assessments dealing with radiological impact in the post-closure period of disposal facilities.

In Italy, only proven and commercially available waste management methods are adopted. Therefore, research is oriented towards examination of options for the future waste management policy.

In the Netherlands, after the completion of studies on disposal of radioactive waste in salt formations, a more generic programme, including studies on retrievability, is now in progress. A further important research topic is transmutation of long-lived fission products and associated activities.

In Spain, the Third Research & Development Plan covering the period from 1995 to 1999 inclusive is currently in progress. The generic and specific objectives of the Plan are predominantly practical in nature, and concern site characterisations, the demonstration of the feasibility of the design and the gathering of knowledge on the performance of the different repository sub-systems over a wide range of conditions and time-scales. Seven major areas of activity are included in the Plan:

- low- and intermediate-level wastes;
- high-level wastes (near-field);
- high-level wastes (geosphere);
- high-level wastes (biosphere);
- high-level wastes (performance assessment);
- radiological protection;
- decommissioning/dismantling of nuclear and radioactive installations.

In Sweden, early research concentrated on the feasibility of safe disposal, later the focus was on site requirements and design of the engineered barrier system. Today the focus is on testing practical site investigation methods and on evaluating the reliability of numerical models. Studying natural analogues provides insights into radionuclide behaviour, and the Oklo mine in Gabon and the uranium ore body at Cigar Lake in Canada are important in this respect. A prime site for testing and study related to disposal in granite is the Äspö underground laboratory.

The majority of the R&D activities in support the radioactive waste management programme in Sweden are carried out by the responsible waste organisation, SKB. They are supplemented by other activities supporting the regulatory activities within SKI and SSI.

The SKB R&D activities are aimed at: building up a good understanding of the phenomena and processes of importance for long-term safety in the deep geological disposal of radioactive waste; refining models for essential processes in the repository; building up the necessary databases, including data on site comparisons, in preparation for the planned site investigations in order that the performance and safety of the repository can be evaluated.

A report on the programme is produced every third year. It gives an account of the present state of the knowledge within the Swedish programme, an overview of all the actions required to implement a safe management of radioactive waste in Sweden, and a somewhat detailed account for the planned activities for the coming 6 years. The most recent report is the SKB 'R&D Programme 95', published in September 1995. Before the reports are accepted as a base for future activities, they are submitted to an extensive review by the authorities and centres of knowledge in Sweden. The programme and the results of the review form the basis for conclusions and guidance from the Swedish Government.

The R&D programme will be adapted to reflect the progress made in the repository project, and although the amount of project related research will necessarily diminish with time, this does not mean it can be dispensed with altogether. Integrated experiments, practical tests and site-specific bedrock investigations are expected to continue in order to improve data quality and understanding in certain areas. For example, one specific area is the prediction of probable future repository evolution, without introducing pessimistic simplifications. Another would be the better quantification of the safety margins in present-day designs.

The Nordic countries co-operate within NKS (Nordic Nuclear Safety Research) on various R&D aspects of radioactive waste management.

The United Kingdom's research policy, as set out in the 1995 White Paper "Review of Radioactive Waste Management Policy: Final Conclusions" is that each of the component parts of the industry, regulatory bodies and Government should be responsible for commissioning and funding the research and development necessary to support their respective functions in relation to radioactive waste management. There are national arrangements for liaison in respect of these research activities. The major element of current activity is the research relating to construction of a repository for intermediate-level and high-alpha content low-level waste. The Government is also starting work on developing a research strategy for the eventual disposal of high-level waste and spent fuel.

4. Safety of Radioactive Waste Management in the European Union

As with other activities involving ionising radiation, the safety of radioactive waste management is based on the well-known principles of radiation protection; namely, justification of a practice, dose limitation for individuals and optimisation. The justification for radioactive waste management practices is a consequence of the justification of practices giving rise to the waste. Concerning optimisation, the application of this principle is highly complex in the case of disposal of long-lived waste, where exposures of the population may be expected in the distant and very distant future, and where the uncertainty inherent in assessments is rather large. In the previous, third, report, principles for ensuring safety were described, and the regulations, directives and recommendations issued by international and national bodies in order to ensure a high level of protection for workers and population were summarised. The present chapter completes and up-dates this information.

4.1 Regulation and control

4.1.1 The international scene

Legal and regulatory measures applicable in radioactive waste management stem from a few common fundamental principles. These principles are all subject to recommendations by international bodies and concern essentially:

- radiological protection;
- ethical and sociological questions;
- protection of the environment and natural resources;
- nuclear safeguards.

The international recommendations have been implemented in detail in the Union and national legal framework.

The activities of the different international bodies acting in the field of radioactive waste management are presented in Sections 4.1.1.1 to 4.1.1.4.

4.1.1.1 The International Commission on Radiological Protection (ICRP)

This body issues recommendations on the safe use of radiation. Basic recommendations are in ICRP-26 (and its revision), introducing individual dose limits; ICRP-46, relevant to underground disposal of solid radioactive waste (introduces risk limits for probabilistic situations); ICRP-60, extending the system to protection against potential exposures; ICRP-64, with an overall framework for potential exposures. An expert group is currently working on more precise formulations for applying the ICRP-46 recommendations; the areas under consideration are:

- how to handle uncertainties in the calculation of doses and risks;

- how to consider the long-term safety of passive systems, where no verification is possible and no intervention is either desirable or foreseeable;

- the formulation of criteria and how to demonstrate compliance.

4.1.1.2 The International Atomic Energy Agency (IAEA)

This UN agency has considerable acquired experience and knowledge in the field of radioactive waste management, and establishes and promotes, in a coherent and comprehensive manner, the basic philosophy and steps necessary to implement this information as part of its RADWASS (Radioactive Waste Safety Standards) programme. These standards provide Member States with guidance on implementation, and are a complement to national criteria, standards and regulations. The recommendations relevant in the field radioactive waste management appear under Safety Series 111. The main standards either adopted or in an advanced draft version are:

- Safety Fundamentals: i.e. principles of radioactive waste management (111-F).

- Safety Requirements: establishing a national system for radioactive waste management (111-S-1); pre-disposal management of radioactive waste (111-S-2); near-surface disposal of radioactive waste (111-S-3); decommissioning of nuclear facilities (111-S-6).

- Safety Guides: covering items such as siting of repositories and application of clearance levels.

Furthermore, the Safety Practices series deals with application of principles and practices, and documents in the TECDOC series are intended for discussion of particular technical and scientific topics.

General principles for radioactive waste management are laid down in the Safety Fundamentals in 9 'commandments', covering:

- protection of human health;

- protection of the environment;

- protection beyond national borders;

- protection of future generations;

- burdens on future generations;

- national legal framework;

- control of radioactive waste generation;

- radioactive waste generation and management interdependencies;

- safety of facilities.

These principles apply to all aspects with the exception of activities where another international instrument exists, for example the transport and export and import of nuclear material.

4.1.1.3 OECD Nuclear Energy Agency (NEA)

This organisation aims at furthering the peaceful uses of nuclear energy by sponsoring studies and projects and by increasing the compatibility of safety and regulatory policies of its Member States. The Radioactive Waste Management Committee (RWMC) carries out a programme dominated by work on long-term performance assessment of radioactive waste repositories with related safety issues, and on the evaluation of potential disposal sites. The waste management situation has been evaluated in three so-called Collective Opinions, addressing techniques, safety assessments and ethical issues. Two working groups, the Performance Assessment Advisory Group (PAAG) and the Co-ordinating Group on Site Evaluation and Design of Experiments for Radioactive Waste Disposal (SEDE) are interacting closely, and jointly sponsor several projects. Other activities are related to radionuclide transport in geological heterogeneous media, and the maintenance of important databases. In the regulatory field, NEA has been deeply involved in the analysis of possible scenarios of future human intrusion in disposal facilities.

4.1.1.4 International Conventions

There are a number of International Conventions that have implications for radioactive waste management practices world-wide.

Recently, on October 24th 1996, the "Convention on Nuclear Safety" entered into force. This Convention entails a commitment to the application of fundamental safety principles to nuclear installations. It covers storage, handling and treatment facilities for radioactive materials as long as they are on the same site as a land-based civil nuclear power plant and are directly related to the operation of the plant. In the chapter on obligations, it is specified that "the generation of radioactive waste from the operation of the nuclear installation is kept to the minimum practicable for the process, both in activity and volume". The Convention also affirmed, in the preamble, "the need to begin promptly the development of an international Convention on the safety of radioactive waste management". The precondition for this, namely the adoption of the IAEA Safety Fundamentals, having been fulfilled, a group of legal and technical experts was convened in order to prepare such a convention.

The "Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management" has been open for signature by the contracting parties since September 1997. At the end of February 1998, the Convention had been signed by the following Member States: Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Sweden and UK. The preamble recognises the right of any state to ban the entry into its territory, and subsequent disposal, of foreign waste, but also recognises that in certain circumstances safe management of radioactive waste might be fostered through agreements between states. A number of obligations have been formulated, covering mainly safety requirements, the need for a regulatory body, siting, design and operation of facilities, and institutional measures. At review meetings, each contracting party submits a national report, which describes its policies, waste management, criteria used to define radioactive waste, and measures taken to implement the Convention. An inventory of radioactive waste is also required.

Several conventions deal with the prevention of marine pollution through the sea disposal of radioactive and non-radioactive material. Of particular interest here is the Convention on the prevention of marine pollution by disposal of wastes and other matters, which entered into force in 1975 and allowed some sea-dumping in the North Atlantic. Later, in 1983, a 25-year moratorium on disposal practices was adopted. Other Conventions in this area are the Oslo, the Helsinki and the Barcelona Conventions, which are valid for specific oceans.

4.1.2 Community legislation and recommendations

A full description of principles and implementation of standards is available in the following EUR reports: "Objectives, standards and criteria for radioactive waste disposal in the European Community" (EUR-12570) and "Policies, regulations and recommendations for the decommissioning of nuclear installations in the European Community" (EUR-15355). A description of relevant Directives is also included in the above reports. For this reason only a brief mention of existing legislation and an up-date of new developments will be included in the present report. The Communities issue regulations that are directly applicable in all Member States, these *directives* must be implemented in national legislation within a prescribed time-limit, and also issues recommendations to the Member States.

The basis of European law is established in the European Community Treaties. In particular, the majority of legislation dealing with nuclear matters is found in the EURATOM Treaty, though other relevant legislation can also be found in the EEC Treaty and supplement, the Single European Act. The Basic Safety Standards for the protection of health of the general public and workers against the danger of ionising radiation are laid down in Directive no. 80/836 of 15th July 1980. The key measures introduced in this Directive are the limitation of doses through the imposing of a maximum dose in national regulations, requirements regarding notification and licensing of sources, practices and facilities, and reporting levels enabling possible exemption from prior authorisation for the handling and disposal of radioactive wastes. The Council adopted an important revision of the Basic Safety Standards on 13th May 1996 (Directive 96/29/EURATOM); the provisions of this directive have to be implemented in national regulations before 13th May 2000. Some particular features are: dose limits for workers have been reduced to 100 mSv over five consecutive years, with a maximum of 50 mSv for any single year; effective doses to members of the public are limited to 1 mSv per year; introduction of radionuclide-specific reporting levels and authorisation of practices. The radiological risks associated with sources of natural radiation are also considered in the Directive, but implementation of measures to protect against these hazards have been left in the hands of the national safety authorities. In addition, principles for defining activity levels for recycling of material outside the nuclear sector and for clearance of very low-level radioactive material are provided.

The Basic Safety Standards also mention, in general terms, transport of radioactive substances. Model regulations for the safe transport of radioactive waste were first drawn up by the IAEA in 1961 and have been regularly updated since. They are implemented in the national regulatory system of all Member States, and their effectiveness in ensuring a high level of safety has been demonstrated. Euratom has established a system of supervision and control of international shipments of radioactive waste (no. 92/3/EURATOM of 3rd February 1992); those countries or areas not having a regulatory system comparable with that in Union Member States are excluded from being the final destination of radioactive waste transports. Regular reports, drafted by a standing working group, are produced on the implementation of these measures.

The Directive no. 85/337/EEC of 27th June 1985 requires that a range of nuclear installations, and in particular radioactive waste repositories, be subject to an environmental impact assessment (EIA). An amendment (Directive 97/11/EEC of 3rd March 1997) extents this requirement to include interim storage facilities in which the storage duration for radioactive waste is planned to be in excess of 10 years. This amendment has to be introduced in national legislation by 14th March, 1999. The directive also introduces measures encouraging the involvement of the public in the EIA process by requiring information to be made readily available and by promoting opportunities for pubic debate.

Finally, safeguarding of fissile and source material as laid down in the EURATOM Treaty is subject to reporting as specified in Regulation 3227/76 EURATOM. Discarded quantities of fissile and source material no longer suitable for further nuclear use in the nuclear fuel cycle are subject to EURATOM safeguards until exemption from further controls is agreed by the safeguarding authority.

4.1.3 National controls of radioactive waste management in the EU Member States

Complementary information can be found in the relevant sub-sections in Section 3.2. The reader is also referred to the published proceedings of an NEA international workshop "Regulating the Long-term Safety of Radioactive Waste Disposal", Córdoba, Spain, 20-23rd January 1997, for more complete information concerning the regulatory structure in the different countries.

In Belgium, as laid down in legislation, ONDRAF/NIRAS is responsible for the treatment/conditioning of radioactive waste from producers who lack appropriate installations of their own. ONDRAF/NIRAS is also responsible for storage and final disposal of all conditioned wastes including spent fuel. The Government grants licences for waste management facilities, and the Ministry of Economic Affairs oversees the implementation of the national waste management policy. Responsibility for the regulation of nuclear safety rests with the Ministry of Interior Affairs. ONDRAF/NIRAS also has a role overseeing plans for decommissioning, and is responsible for decommissioning nuclear facilities considered liabilities from the past.

In Denmark, the responsibility for the waste rests with the producer until the waste has been transferred to and accepted for storage at Risø National Laboratory.

In Finland, legislation states that the producers are fully responsible for the implementation and financing of activities concerning the management of their radioactive waste. The two nuclear utilities founded a jointly owned company, Posiva Oy, to manage the planning, R&D and future implementation of the final disposal of spent fuel. The Government grants licences for radioactive waste management facilities, and the Ministry of Trade and Industry oversees the corresponding planning and implementation in order to ensure that all aspects are carried out in a timely manner and in accordance with the national radioactive waste management policy. The responsibility for the regulation of nuclear safety, including radioactive waste management, rests with the Finnish Centre for Radiation and Nuclear Safety (STUK).

In France, owing to the extent of the nuclear activities, it was decided that a special organisational system was required, with regulations specific to nuclear safety. The key element in this system is the technical responsibility of the operator. The public authorities ensure that this responsibility is fully assumed in compliance with the relevant regulatory provisions. The definition and implementation of nuclear safety policy is the responsibility of DSIN (Direction de la Sûreté des Installations Nucléaires), which answers to the Minister for Industry and is placed at the disposal of the Ministry for the Environment. All the main permanent nuclear installations (except classified facilities working on national defence projects) fall under the jurisdiction of the DSIN, including those for storage and disposal of radioactive waste. The legal base for these regulatory activities is the Decree of December 1963 establishing the licensing process, and the Waste Act of 30th December 1991. DSIN controls the safety of radioactive waste management through direct inspection of the various installations involved, as well as through checks and verifications of ANDRA's activities.

In Germany, the Atomgesetz (Atomic Energy Act) confers responsibility for disposal of radioactive waste on the Federal Government, with the BfS (Bundesamt für Strahlenschutz) as the responsible authority. The BfS is a federal agency, established in 1989, operating within the BMU (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit). The Federal States are responsible for the licensing of all nuclear installations, including those dealing with radioactive waste, with the BMU acting as the supervisory body. In this role, the BMU is advised by the Commissions dealing with reactor safety and radiological protection.

In Italy, the responsibility for the management of nuclear waste lies with the large producers, i.e. ENEL and ENEA, who treat and condition the waste in compliance with the criteria for final disposal. Low-level wastes produced in medicine, research and industry are collected, treated and conditioned by NUCLECO S.p.A. on behalf of ENEA, using facilities made available by ENEA. All activities related to radioactive waste are subject to control by ANPA.

In Luxembourg, radioactive waste, arising essentially from use of radioactive sources in industry, has to be returned to the source supplier. If this is not possible, the spent sources have to be sent to a radioactive waste disposal facility in a neighbouring country. The conditioning of the radioactive waste, as well as the financial charges, are the responsibility of the user. The Radiation Protection Department of the Ministry of Health is the regulatory authority responsible for the licensing of all transport and for radiation protection aspects. This authority also co-ordinates, with the relevant foreign authorities, the transport of small producers' radioactive waste to foreign disposal facilities.

In the Netherlands, all activities involving radioactive materials are regulated by the Nuclear Energy Act. Licensing is the competence of the Ministry of Economic Affairs, the Ministry of Housing, Spatial Planning and Environment, the Ministry of Social Affairs and Employment and the Ministry of Health, Welfare and Sport. Nuclear activities are subject to control by the Nuclear Inspectorate and the Environmental Inspectorate. All use of radioactive materials are subject to licensing under the Nuclear Energy Act, and the Act stipulates that a licensee can only dispose of his waste by handing it over to the authorised radioactive waste management organisation; COVRA is the only such organisation authorised by the Dutch Government.

In Spain, the Empresa Nacional de Residuos Radiactivos S.A. (ENRESA) was set up in 1984 as a state-owned company with responsibility for all radioactive waste management activities in the country. The Government has control over ENRESA's activities through the Ministry of Industry and Energy. Large waste producers are responsible for conditioning the radioactive waste they produce, while ENRESA is responsible for conditioning the radioactive waste from small producers. ENRESA is responsible for the collection and transport of radioactive wastes in general, as well as for the design, construction and operation of the centralised storage and disposal centres. ENRESA's other areas of responsibility are decommissioning and dismantling of nuclear facilities, and the conditioning and rehabilitation of uranium mining and milling facilities, when required. ENRESA operates on a contractual basis with the radioactive waste producers, and each contract stipulates the relevant radioactive waste acceptance requirements. From the regulatory point of view, the Nuclear Safety Council is the only body responsible for radiation protection and matters of nuclear safety. All licenses issued by the Ministry of Industry and Energy must comply with Nuclear Safety Council rulings.

In Sweden, legislation unequivocally places the responsibility for the nuclear waste on the producer, i.e. the utilities themselves and their jointly owned waste management organisation, SKB. The producer is to take all necessary actions to ensure safe management of the waste. The two main regulatory authorities are the Swedish Nuclear Power Inspectorate (SKI) and the Swedish Radiation Protection Institute (SSI). Both SKI and SSI are responsible for supervising radioactive waste management operations, and are developing regulations dealing with the related safety and radiation protection issues.

In the United Kingdom, the Nuclear Installations Inspectorate regulates the handling of radioactive waste on nuclear sites as part of a wider responsibility for on-site operations. Before any site is licensed, the Inspectorate must be satisfied that the operator can run the site safely and that liabilities will be dealt with. Discharges and off-site disposals of waste require separate authorisations from the Environment Agency (in England and Wales), the Scottish Environment Protection Agency (in Scotland), and the Environment and Heritage Service (in Northern Ireland). Before granting such an authorisation, the Agencies are required to consult relevant local authorities, water undertakings and other public or local bodies as appropriate. The transport of radioactive materials, both between nuclear sites and to disposal facilities, is also regulated. The use of radioactive materials on non-nuclear sites and operation of mobile radioactive apparatus must be registered, and the accumulation and disposal of radioactive waste from such activities must be authorised by the Environment Agencies.

4.2 Safety case for disposal

Handling, storing and the operational and institutional control phase of disposal of radioactive waste is well regulated and controlled. Short-lived radioactive waste in on- or near-surface facilities requires institutional control for some centuries; afterwards, the radioactivity having decayed to natural background levels, no further restrictions are needed. For radioactive waste types needing isolation from the biosphere (and man) over a very long time-span, disposal in deep geological formations in the preferred option in the EU Member States. In such repositories, protection is provided by a multi-barrier system, one of the barriers being the host rock formation itself. The safety of such a passive system depends on the ability of these barriers to isolate the waste from the biosphere over long periods of time. Safety assessments are made by studying the events and processes leading to eventual breakdown of the barriers and subsequent release of radionuclides from the packages into the groundwater and hence the biosphere. Such events would include human intrusion scenarios.

4.2.1 Performance assessments

A performance assessment has to be made at a rather early stage in the design of a repository, because the outcome will influence site selection, concept development, system optimisation and facility design. It will also define the site characterisation programme and the required engineered barrier performance, and will be of considerable importance for development of radioactive waste package specifications and radioactive waste acceptance requirements. The calculation of performance indicators, in terms of impacts on human health and the environment, is accomplished using mathematical models simulating radionuclide transport to man. The results are compared with safety indicators, the most important being radiation dose and risk to man. Approaches can be deterministic for normal evolution scenarios and probabilistic in the case of possible events.

A number of methodologies have been developed and applied, either to specific or generic sites; an example is the PAGIS (Performance Assessment for Geological Isolation Systems) methodology developed with the support of the Commission's R&D programmes. The features, events and processes to be considered in these methodologies have been listed in IAEA-Safety Series 111-G-4.3; they include:

- events related to the natural environment;
- human activities;
- effects of the waste on the repository.

An assessment of the long-term safety provides the safety-related basis for key decision-making, licensing issues, and so on, during the development of the actual repository. The general approach to safety assessment consists of a number of interrelated elements:

- identification of the relevant safety criteria and design principles;
- identification of a disposal system and of a site;
- identification of possible interactions within the repository system and between the repository and its environment;
- identification of future evolution or events influencing the safety of the repository;
- development and application of appropriate models;
- qualitative or quantitative evaluation of repository performance with time;
- uncertainty and sensitivity analysis;
- comparison of results with acceptance criteria.

The assessment methodology is certainly well developed, but the uncertainty associated with events occurring in the very far future makes proof of compliance with safety indicators or requirements difficult.

4.2.2 Retrievability

Although not a generally accepted principle, regulations in a number of countries have raised the issue of retrievability of radioactive waste emplaced in a deep geological repository. The initial motivation for introducing retrievability is a political one, since it is thought to be a positive influence on the public acceptance of a repository on a particular site.

The advantages of retrievability are:

- removal is possible in case of unforeseen events;

- transmutation of the long-lived radioactive waste could still be practised at some time in the future, if techniques became available;

- extraction of valuable material from the waste would still be possible in the future, if new processes became available;

- for a limited period of time, performance assessment models could be verified using the real repository;

- future generations will retain the option of taking remedial action, depending in the advances made in science and technology.

The drawbacks of full retrievability (i.e. access to radioactive waste without major geotechnical intervention) are that the benefit of the geological isolation barrier is lost, and that institutional control, surveillance and maintenance are needed on a continual basis to provide sufficient safety. Clearly, institutional control can be expected to be assured for a period of a few hundred years, but eventually final closure will have to be accomplished. For certain host rock, a better solution might be to close the repository immediately after the operational period and only to retrieve the waste by intervention from the surface if necessary. However, this solution may entail additional costs, because in order to permit retrieval in an undamaged state, the waste packages would have to be designed to resist the pressure and corrosion resulting from complete burial and back-filling.

4.2.3 Intrusion

A particularly awkward problem is how to deal with unintentional, or intentional, intrusion into a deep repository for high-level waste. Currently, regulators impose rigid individual dose limits without taking into account the probabilistic nature of the event. The most probable intruder will be a member of a drilling team, who will take drilling cores and analyse them in a field laboratory. In the case of intrusion during approximately the first thousand years after the closure of the facility, the intruder(s) will receive doses in excess of individual dose limits. A number of active and passive measures have been examined in order to avoid such a scenario, and some sort of knowledge transfer for periods up to 10,000 years, together with a prolonged period of institutional control, have been proposed. Nevertheless, there is a consensus that intrusion cannot be excluded completely.

4.2.4 Institutional control

An operational system of institutional control, including safeguards for radioactive waste containing fissile material, is a pre-condition for safe interim storage. Such control is envisaged for periods up to a few hundred years, followed by measures to assure a transfer of knowledge up until 10,000 years (e.g. by means of markers). Most near-surface disposal facilities have to remain under active control after closure for up to a century (or more, depending on the waste inventory), followed by a period of passive control of land use. In the case of deep repositories, active control could cease immediately after closure of the repository (i.e. back-filling of galleries and access shafts). However, the authorities will probably continue air and water monitoring in order to alleviate public concerns, and some safeguards measures may continue to apply to repositories containing spent fuel.

4.3 Current developments

There are two key areas where major regulatory development is required: firstly, in the support of the long-term disposal of radioactive waste; secondly, clearance levels for very low-level radioactive material.

Research and development is continuing in order to define characteristics of all elements of the disposal system and to examine, amongst others, material and migration parameters.

In the case of performance assessments over very long time periods, research into natural analogues may provide useful assistance in the formulation of appropriate regulations.

The main outstanding regulatory issues have been discussed by the IAEA within the Working Group on Principles and Criteria for Radioactive Waste Disposal. Items considered include:

- the definition of critical groups and biospheres in the context of radioactive waste disposal;
- regulatory decision-making in the presence of uncertainty and complexity;
- the approach to the treatment of human intrusion;
- management of long-lived low-level wastes.

Clearance levels for very low-level radioactive material exist in most nuclear installations as part of the plant license for normal operation, and for certain projects such as major dismantling operations, where case-by-case procedures may be agreed with the safety authorities. General rules have been developed, based on a reference dose per practice of roughly 10 μSv/a or less for individuals in a critical group, and on a collective dose per practice of 1 man-Sv, without optimisation. The aim, of course, is to be able to translate these values into actually applicable concentrations and surface contamination limits. Scenario calculations have permitted the IAEA and EURATOM to issue recommendations on exemption levels for groups or categories of radionuclides. A EURATOM working group has drafted radiological protection criteria for the recycling of metals from the dismantling of nuclear installations. These criteria include radionuclide-specific values and have the status of recommendations, with account taken of advice from the so-called Article-31 (EURATOM) Group of Experts.

A major effort has to be made, both at IAEA and Union level, to improve implementation of clearance levels in radiation protection regulations. This has already been achieved in certain EU Member States (e.g. Finland and Sweden). Clearance levels have a paramount effect on the quantities of radioactive waste produced during decommissioning of nuclear installations. Moreover, large differences in clearance levels and practices between EU Member States is not acceptable if there is to be an open market for scrap or recycled metal; material released in one country should be accepted for further use in another. Finally, a broadening of the recommendations to include the concrete from dismantling of nuclear installations is also necessary.

5. Financial Aspects and Liabilities

5.1 Costs, financial provisions and ownership of radioactive waste

This chapter adds to the information on financial matters regarding storing and disposing of radioactive waste presented in the previous report. It also indicates at what point the ownership of waste and the liability for future costs change. Costs for treatment and conditioning of waste are generally excluded, since they are considered, at least by the large producers, as part of the normal operating costs of the plant. Most figures presented below are those communicated by EU Member States to OECD/NEA. It is expected that a complete report on disposal costs for low- and intermediate-level waste in OECD Member States will be published in 1998.

5.1.1 Austria

Radioactive waste is treated and conditioned (and occasionally collected) by the Research Center at Seibersdorf. A moderate fee, depending on the service provided, is charged. Investment in the facilities at Seibersdorf has been financed out of the general state budget. Conditioned radioactive waste and packaged spent sealed sources are stored at Seibersdorf at no extra cost to the initial owner. Further costs and liabilities are met by the State.

5.1.2 Belgium

In Belgium, large producers may treat, condition and store radioactive waste. The radioactive waste management agency, ONDRAF/NIRAS, operates its own processing facilities. All radioactive waste presented to the agency by Belgian producers has to be accepted if it satisfies the specifications laid down by ONDRAF/NIRAS. Producers build up and manage their own funds to cover the expected costs for transferring radioactive waste to the agency. Tariffs charged by the agency are calculated from the expected costs in a given fiscal year, which include the costs of construction of agency facilities originally paid for with loans to ONDRAF/NIRAS (the exception is storage building 36 at Dessel, which has been financed directly by the electricity producers).

Tariffs for treatment of low- and medium-level raw waste are 27,000 ECU/m^3, with values up to a factor of 10 lower for inorganic liquids.

Tariffs for storage of short-lived waste (suitable for an on-surface repository) are 1,300 ECU/m^3, and for long-lived waste are 2,600 ECU/m^3. The tariff for disposal of short-lived waste has been calculated as 7,000 ECU/m^3, and long-lived waste has been accepted and taken over by the agency for a tariff of 13,000 ECU/m^3. Whenever radioactive waste has been handed over to the agency, it becomes the property of the agency and all liabilities are transferred. Payments and tariffs applicable to larger producers storing radioactive waste on their own premises have not yet been settled, but conditioned waste costs will be considerably higher than values indicated above. Fees collected to cover the costs of disposal are managed by ONDRAF/NIRAS in a special fund.

From 1997, the return of vitrified high-level waste from reprocessing is expected. The storage facility, building 36 at Dessel, has been financed with 67 MECU provided by the large producers. Costs for long-term storage and later deep disposal have been estimated at about 350,000 ECU/m^3.

5.1.3 Denmark

Management of Danish radioactive waste is carried out by the State-owned Risø National Laboratory at Roskilde. According to rules laid down by the National Institute of Radiation Hygiene, Danish users of radioisotopes have to deliver their waste to the Waste Management Plant at Risø, where it is treated and stored together with waste from the research centre itself. As soon as the waste has been transferred, the State becomes the owner and takes over liability. Tariffs paid by producers cover treatment, conditioning and long-term storage. Presently the fee is 23.5 ECU/kg for solid material, or approximately 2,350 ECU per conditioned 200-litre drum ready for storage or disposal. In the case of spent sealed sources, appropriate fees for dismantling are charged.

5.1.4 Finland

The large producers TVO and IVO are fully responsible for the radioactive waste they produce, including the disposal of the waste. A fund covering all costs is built up with annual waste management fees calculated each year from the assessed waste management liability of the utilities. The fund is Government managed, but utilities may borrow back up to 75% of the capital against securities. The utilities perform radioactive waste treatment and conditioning at their facilities, and own their own disposal facilities for all types of low- and intermediate-level waste. At the TVO site at Olkiluoto, disposal costs (including closure) are close to 4,800 ECU/m^3. For the similar repository at Loviisa operated by IVO, a somewhat lower price, close to 3,700 ECU/m^3 is expected.

Small producers have the possibility to hand over their waste, against a modest fee, to the state-owned STUK centre. Radioactive waste from small producers is temporarily stored on the premises at the TVO repository; at a later date, it is planned to dispose of most of this waste in the vaults of that repository.

Disposal of spent fuel will be managed by Posiva Oy, a company jointly owned by TVO and IVO, and will take place in a common deep repository. Total costs of disposal of the 2,600 tU of spent fuel, plus some other highly active waste, are expected to be in the region of 600 MECU (this corresponds to less than 230,000 ECU/tU without discounting).

5.1.5 *France*

In France, the state-owned agency ANDRA designs, builds and operates repositories for radioactive waste. All radioactive waste suitable for disposal in an existing repository has to be handed over to ANDRA, which sets up acceptance criteria. Since only surface repositories exist at the moment, disposal is limited to short-lived waste. Radioactive waste transferred to ANDRA changes ownership and liabilities are taken over by the agency. For radioactive waste which cannot be transferred to ANDRA, and which is still at the producer's or the reprocessing site, funding has to be set aside by the producer, though he can use these funds in his own investments.

Concerning the operating facility at Centre de l'Aube facility, initial fees (not including investment and capital costs) were 1,460 ECU/m^3. As the arisings are diminishing, specific costs could rise to 2,300 ECU/m^3.

Small producers pay slightly lower tariffs than large producers on radioactive waste transferred to ANDRA. No cost estimates for disposal of long-lived and high-level waste are given. The building of the three underground laboratories will require an investment of about 409 MECU, with the estimated annual operating costs per laboratory being 4.6 MECU.

5.1.6 *Germany*

In Germany, the BfS is by law responsible for design, construction, and operation of repositories. The Atomic Energy Act states that, in general, producers are liable for their radioactive waste until it is accepted by BfS for disposal and transferred to the repository. Most large producers store radioactive waste at their own facilities. Only a few central storage facilities (Ahaus, Gorleben, Jülich and Greifswald) allow storage of spent fuel. Transfer to these central facilities or repositories cannot be enforced. Small producers have to forward their radioactive waste to a regional collecting/storage depot (Landessammelstelle) of their Federal State (Land) where, through payment of a fee, the producer can pass on ownership of and responsibility for the waste. Until 1994 the tariff for small producers was 500 ECU per 200 litre drum; this has now risen to 1,250 ECU per 200 litre drum to be disposed of in the ERAM repository, and to 2,500 ECU per 200 litre drum to be disposed of in the planned Konrad repository.

The only operating repository is the one situated at Morsleben, where specific disposal costs of 6,250 ECU/m^3 have been calculated. It should be noted that this repository was constructed at a relatively low investment cost by the German Democratic Republic. In the case of the Konrad repository, whose license is expected to be granted soon, and which has capacity for up to 650,000 m^3 of non-heat-generating waste, a cost of disposal of 12,000 ECU/m^3 has recently been calculated. Disposal of high-level heat-generating waste is only planned to take place at the Gorleben salt dome. Estimated costs of construction for the entire repository are 2,200 MECU, with operating costs of approximately 30 MECU/year.

All large producers of radioactive waste run tax-exempted reserve funds, which may be used for their own investments. German nuclear power plant operators have earmarked about 15,000 MECU for storage, reprocessing and disposal of their spent fuel and all types of radioactive waste.

5.1.7 Italy

In Italy, it is the responsibility of the large producers to treat, condition and store their nuclear waste. NUCLECO S.p.A, on behalf of ENEA, collects, treats and stores low-level radioactive waste from small producers.

Small producers pay a tariff for treatment and storage of radioactive waste on transfer to NUCLECO. The charges are in the region of 2,500 ECU/m^3, which also covers disposal costs estimated at 1,200 ECU/m^3 of conditioned waste.

5.1.8 The Netherlands

The waste agency COVRA is owned by the three large waste producers (each with a 30% shareholding) and the Government. In the shareholders' agreement, it is stipulated that COVRA will conduct its financial affairs so that all costs are covered by the fees paid for the radioactive waste transferred to the agency. The fee includes all direct costs for transport, conditioning and storage, and also all financial provisions for the costs of future storage and eventual disposal. COVRA takes over full title of the radioactive waste, and fees paid will not be adjusted retrospectively.

Future disposal costs will be covered by money placed in a capital growth fund. This money is included in the fee paid at the time of transfer of the radioactive waste to COVRA. The fund then has to grow to the required level during the long period of interim storage, and in this respect its performance will be analysed periodically. One deep repository is foreseen, suitable for all low- and medium- as well as all high-level waste. The estimated costs are 1,500 MECU, of which one third has to be covered by fees from low- and medium-level waste, and two thirds from high-level waste.

For those large producers who condition their own radioactive waste, the fees at the time of transfer to COVRA vary between 8,200 and 16,000 ECU/m^3. In the case of unconditioned waste from small producers, the fee charged depends on the treatment desired and on the volume resulting after treatment. For a 100 litre drum of solid radioactive waste, a fee of between 400 and 2,000 ECU is charged.

For high-level waste (mostly vitrified and other reprocessing waste), a dedicated storage building will be constructed for which it is expected an investment of 115 MECU will be required.

5.1.9 Portugal

Radioactive waste is managed by the Department of Radiological Protection and Safety (DPSR) of the General Directorate for the Environment. After the waste is collected by the DPSR, the Government takes over ownership and all liabilities.

A moderate fee, depending on the type of radioactive waste involved, is collected from the producers for the treatment, conditioning and interim storage of radioactive waste. Costs for future long-term storage and later final disposal are not charged; these costs will be supported by the Government.

5.1.10 Spain

Radioactive waste management is the task of ENRESA, a limited liability organisation with state-owned shareholders. ENRESA's responsibilities cover all aspects of radioactive waste management, including decommissioning of nuclear installations and remediation work at uranium mining and milling sites. ENRESA has signed several agreements with the large radioactive waste producers to promote the introduction of processes to minimise waste arisings at source.

Large waste producers have no obligation to hand over radioactive waste to ENRESA, though in any transfer a contract has to be concluded, and waste has to meet acceptance criteria established by ENRESA. The fees paid to ENRESA generate sufficient funds over the NPP operating lifetimes to cover the costs associated with management of all radioactive wastes produced by each plant and with eventual dismantling and decommissioning. The fee, or levy, is calculated as a percentage of the total revenue from sale of electricity; it is revised annually by ENRESA and has to be approved by the Government. In 1997, the applied percentage was 0.8%.

As soon as radioactive waste is transferred to and accepted by ENRESA, it assumes all responsibilities and future liabilities. All radioactive waste suitable for on-surface disposal is disposed of at the El Cabril facility; long-lived waste is stored at the producers' sites. Small producers have to pay a tariff depending on the type of radioactive waste. Producers outside the nuclear electricity generation system typically pay a tariff of 2,000 ECU/m^3, and charges of between 230 and 440 ECU per spent sealed source are applicable for small producers.

Specific costs, covered by the fund, for disposal of radioactive waste from large producers have been estimated at close to 3,000 ECU/m^3. For deep disposal of long-lived radioactive waste, vitrified waste from reprocessing of spent fuel from Vandellos-I, and direct disposal of all other spent fuel, an investment of about 2,500 MECU is estimated to be required (including siting and underground laboratory research).

5.1.11 Sweden

In Sweden, the Act on Nuclear Activities states that the radioactive waste producers have the full responsibility for the management and disposal of the spent fuel and radioactive waste. The largest radioactive waste producers are the nuclear utilities. They have formed, and jointly own, SKB, the company charged with the management and implementation of this work. The utilities, however, remain owners of the radioactive waste at all times and retain responsibility and liability for future expenses.

SKB is partly state-owned (58%) because Vattenfall, the largest utility, is a state-owned company. SKB operates, however, as a private company. By using sub-contractors to execute the operational programme on its behalf, SKB can manage the implementation of the radioactive waste management programme with a relatively small staff. For the existing facilities, radioactive waste acceptance is regulated by licenses. Each type of radioactive waste needs to be approved by the safety authorities, SKI and SSI. SKB also takes care of radioactive waste from small producers, after collection and treatment of the waste at the Studsvik research facility.

Financing is provided by levies on nuclear electricity generation to cover specific costs, and by securities against increased costs provided by the reactor owners. The costs associated with waste management and decommissioning are evaluated each year, and the resulting fee per kWh and required securities are specified by the Government. At the present time:

- 0.0014 ECU/kWh are paid to a Government-managed fund to cover fuel cycle costs and decommissioning (0.0003 ECU/kWh are for the latter task);

- 0.00024 ECU/kWh are paid into a utility-controlled fund to cover costs for operational radioactive waste management;

- 0.00018 ECU/kWh are paid as a tax into a separate Government-managed fund to cover costs for clean-up, decommissioning, and spent fuel and waste management from earlier research and development work at Studsvik, Agesta and Ranstad.

Use of the different funds must be approved by the Swedish Nuclear Power Inspectorate.

Short-lived waste is disposed of at the SFR-1 facility at a specific cost of 3,700 ECU/m^3. Long-lived waste and some spent fuel is in interim storage at the power plants. SKB operates an interim centralised storage facility for spent fuel, CLAB, where 310 MECU have been invested; annual operating costs are 12.5 MECU. Research on disposal of long-lived waste and conditioned spent fuel is conducted in an underground rock laboratory at Äspö; construction costs were 62 MECU and annual operating costs 7.5 MECU.

The total costs of the overall Swedish radioactive waste management programme have been estimated at about 6,600 MECU; it is expected that 35% of this figure, or 2,300 MECU, will be for encapsulation and disposal of spent fuel.

5.1.12 United Kingdom

The United Kingdom currently operates two LLW disposal facilities. The larger of these is a near-surface facility at Drigg run by BNFL. This takes short-lived LLW from both the UK nuclear industry and other small users of radioactive substances. In addition, the United Kingdom Atomic Energy Authority (UKAEA) operates a smaller facility for its own wastes at its Dounreay site. Costs for disposal of short-lived LLW at Drigg are 1,600 ECU/m^3 (in 1997), having been much lower in the past.

There are currently no facilities for disposal of ILW and HLW in the United Kingdom, hence the precise costs of disposal of these types of radioactive waste are unknown.

5.1.13 Greece, Ireland and Luxembourg

These countries generate small quantities of radioactive waste in hospitals, research laboratories and industry. None of these countries has plans for final disposal within their national boundaries. In Greece, producers deliver their radioactive waste to a Government-owned institute, and liabilities are then transferred to this Institute against payment of a fee.

5.2 Provisions for decommissioning of nuclear installations

Within the European Union, 39 nuclear power production reactors have already been shut down definitively, and at least 14 plants will be closed down in the next ten years. Additionally, at least 25 critical assemblies, eight pilot reprocessing plants and some older fuel fabrication plants have ceased operation (see table M).

Most of these facilities have been defuelled and placed into a state of 'safe storage'; actual dismantling is delayed for some decades. However, dismantling down to a 'green-field' site has been demonstrated in some pilot projects. It has been shown that full dismantling is technically feasible, and that costs are reasonably low, within the range 10 to 20% of new construction costs.

This section provides information on financing schemes for countries having, or having had in the past, a nuclear power production programme.

5.2.1 Belgium

The utilities are committed to the building up of internal reserves to cover the cost of decommissioning, and this during the nominal plant operation period of 30 years.

The waste agency ONDRAF/NIRAS has assumed the responsibility for 'historical liabilities', in particular the dismantling of the EUROCHEMIC plant and the clean-up of the waste storage area at the CEN/SCK research centre. A government financed fund has been set up to cover expenses.

5.2.2 *Finland*

The utilities make estimates of the costs of full decommissioning of the NPPs, and appropriate fees are collected in a fund managed by the Government. The fees are calculated assuming an NPP lifetime of 25 years and a 75% load-factor.

5.2.3 *France*

The French electricity producer builds up internal reserves to cover decommissioning costs. The calculations assume an operational lifetime of 20 years for gas-graphite reactors and 30 years for pressurised water reactors. Costs for full dismantling of a unit are expected to be 15% of new construction costs.

Costs for decommissioning of installations owned by the Commissariat à l'Energie Atomique (CEA) have to be covered in the annual budget of this public body.

5.2.4 *Germany*

The utilities are building up their own internal reserve funds, which benefit from tax exemptions. For installations in the nuclear research centres, decommissioning costs have to be provided out of the general budget of the host Federal State.

5.2.5 *Italy*

The disadvantage is that nuclear electricity production has now ceased; thus ENEL, the state-owned electricity producer, cannot generate funds for decommissioning from NPP operation.

The Government will cover most of the cost of decommissioning of the ENEL plants, and all costs for the state-owned research facilities.

5.2.6 *The Netherlands*

Both the utilities and the research centres are accumulating internal reserves to pay for the decommissioning of their installations.

5.2.7 *Spain*

Expected decommissioning costs will be covered by part of the fee levied on electricity sales and invested in the fund for radioactive waste management managed by ENRESA. All future expenses will be paid out of this fund.

5.2.8 Sweden

Utilities pay fees on electricity consumption into a government-managed fund that fully covers the expected decommissioning costs.

5.2.9 United Kingdom

The Government has agreed that segregated funds will be set up for decommissioning in those parts of the nuclear industry that are privatised. It is also seeking improvements in the way the unprivatised sections of the industry report on their progress towards decommissioning, in order to help ensure the adequacy of their provisioning arrangements.

6. MISCELLANEOUS ISSUES

6.1 Presence of conventional toxic waste in radioactive waste streams

Radioactive waste is known to contain chemically toxic substances whose toxicity, unlike the radioactivity in the waste, will not decline with time. A number of organic substances, from phenols and PCBs to complexing agents, are present in some liquid waste streams. Asbestos may appear in decommissioning waste. However, the main such contributors are inorganic substances in solid waste: lead in bricks and drums, copper in cables, chromium, nickel, molybdenum and cobalt in steel, beryllium, boron in evaporator concentrates, chromium and nickel in ion-exchange resins. Even low-level waste from normal reactor operation contains significant quantities of cadmium, nickel and selenium amongst others.

In the case of long-lived or high-level heat-generating waste, since deep disposal is envisaged, the presence of chemically toxic substances in the waste is probably not important. However, the regulators may ask for consideration of effects of dissolution and migration of such toxic elements as part of the performance assessment for the repository.

Chemically toxic substances are of importance in low-level waste streams that, from a radiological point of view, are suitable for on-surface disposal, but where the presence of these substances may necessitate deep disposal. Similarly, waste that is exempted because of extremely low levels radioactivity may have a chemical toxicity that is too high to permit release. It should be noted that some disposal facilities already take account of chemical toxicity of the waste. For example, the United Kingdom's Drigg LLW disposal facility already precludes disposal of some chemically toxic wastes, while others are only considered on a case by case basis.

As part of the Community's R&D programme on nuclear fission safety, concentrations of chemically toxic substances in a range of different waste streams have been determined. However, it is difficult to find guidance on what are considered acceptable values for toxic content in waste. Present regulations mention waste concentrations, disposal facility performance levels and, to some extent, environmental quality standards rather than putting emphasis directly on health based parameters. For example, the European Community landfill directive prescribes control measures such as limits on permeability, but does not specify quantitative health protection objectives.

Legislation in Member States relies on specification of plant operating criteria to protect the personnel, or facility design requirements to limit releases or to modify the nature of those releases. Occasionally, particular limits are specified for individual facilities as part of a site license. A higher level of protection has only been suggested in the Netherlands, where the proposed limit on the risk of death in humans is 10^{-5} per year for a wide range of practices, with a limit for a single practice of 10^{-6} per year.

In order to be consistent with the approach for radiotoxic elements, a methodology, which uses the risk assessment methods of the nuclear sector, has been developed and applied ("Application of procedures and disposal criteria developed for nuclear waste packages to cases involving chemical toxicity", EUR-16745). The chosen risk limits are 10^{-6} per year for risks from the inventory of a repository from toxic waste alone, and 10^{-7} per year for a particular regularly exercised practice for a given waste stream. The impact for a number of realistic waste streams was then calculated for a range of scenarios.

Scoping calculations showed that, over the long-term, there were no practical limitations to the concentration of any of the organic substances when generally accepted degradation rates were taken into account. For inorganic substances, the leaching, bathtubbing and environmental change scenarios were the most limiting for shallow or on-surface facilities. These calculations also confirmed that for facilities in deep geological formations, the amounts of inorganic material in actual waste streams were considerably lower than any limiting values likely to be imposed.

From detailed deterministic and probabilistic calculations for shallow facilities it was concluded that:

- the time of occurrence of peak environmental concentrations of inorganics could be affected by the repository closure, but not the magnitude of the peak;

- engineered barriers will affect the timing and magnitude of peak environmental concentrations;

- the release rate of toxic substances is very important in determining the magnitude and time of peak concentrations;

- the bathtubbing scenario could result in higher environmental concentrations than leaching through the base of the facility;

- peak environmental concentrations from leaching might not occur for hundreds or even thousands of years.

The analysis of a large number of typical waste streams shows that shallow disposal may not be desirable for some types of radioactive waste, e.g. large quantities of some decommissioning steels, redundant fuel flasks, copper cables, and asbestos. Nevertheless, more detailed, site-specific assessments may show that shallow disposal is acceptable in particular cases. In conclusion, chemically toxic substances cannot be ignored when the suitability of particular radioactive waste streams for exemption or shallow disposal is assessed.

6.2 Depleted uranium

Depleted uranium is currently considered a possible resource; it is stored mainly at treatment facilities.

There are three material streams to consider:

- tails from enrichment of natural uranium, stored either in the form of UF_6 in special cylinders (at Gronau, Almelo and Capenhurst) or converted to oxide (Pierrelatte);
- uranium from reprocessing, mostly stored in the form of powdered UO_3;
- tails from re-enrichment of reprocessed uranium, stored mainly in the form of UF_6.

In an assessment supported by the European Commission, a survey of quantities has been produced and possible ways of managing the material have been studied ("Study on depleted uranium (tails) and uranium residues from reprocessing with respect to quantities, characteristics, storage possible disposal routes and radiation exposure", EUR-15032).

Huge quantities of depleted uranium are produced; for every kg of enriched light-water reactor fuel that is produced, 5 to 8 kg of depleted material (depending on enrichment) are generated. Large amounts of this material are already stored at the centrifuge enrichment facilities at Almelo, Gronau and Capenhurst, and arisings by the year 2010 are expected to reach 110,000 tonnes.

The possible uses of depleted uranium in the non-nuclear sector are very limited. In metallic form it is used as a counterbalance in aeroplanes and sailing boats, and in the manufacture of some types of ammunition, and there are limited applications as shielding in X-ray or gamma-ray devices. However, much less than 1% of this material is used in the non-nuclear sector.

In the nuclear sector, uses are subject to economic considerations. For example, the enriching of depleted uranium for the manufacture of normal LWR fuel would only be viable when very cheap enrichment processes become available. Furthermore, if this uranium is from reprocessing then it must first be converted to UF_6, and the level of re-enrichment must be increased in order to compensate for the presence of ^{236}U, and new tails will in turn be generated in this process. The most promising route for consumption of uranium from reprocessing is to blend it with plutonium in the production of MOX (mixed oxide) fuel.

A particularly efficient use for depleted uranium would be in the production of blanket fuel for the breeder zone in fast-breeder reactors. However, the introduction of a fast-breeder reactor programme cannot be expected in the short or medium term.

As prospects for economical re-use of all of this material are low, the option of disposal has to be considered. Long-term storage and disposal would require prior conversion to a more stable form, such as UF_4, U_3O_8 or UO_2.

6.3 Waste containing enhanced concentrations of natural radionuclides

The main contributions to human exposure to ionising radiation arise from natural sources - cosmic rays, the radionuclides in the earth's crust and the natural radioactivity of the human body. By comparison, man-made sources are currently responsible for only about 10%, on average, of human exposure. The levels of naturally occurring radioactivity in the formations that make up the earth's crust and in other materials in the environment vary widely, and some of these materials extracted for use in industry contain non-negligible concentrations of radioactivity. In some instances, industrial processing can lead to further enhancement of the concentrations, either in the product or in waste materials. It must be emphasised that these waste materials are, with some exceptions, not considered as being radioactive waste. This situation may change with the implementation of the already mentioned revised Basic Safety Standards (Directive 96/29/EURATOM), which introduces nuclide-specific reporting levels, even for radionuclides of natural origin. The practical implementation of these levels is the responsibility of national authorities.

Because of possible concerns over the radiation exposure that could result from the handling of such materials and from the use or disposal of the wastes, the European Commission has supported a programme of work in this area over a number of years and has assembled a substantial body of information by means of study contracts and contributions from experts. This section of the present report mentions the most important industrial activities or processes leading to possibly significant exposure.

More detailed information may be found in the Commission's report on the subject: "Materials containing natural radionuclides in enhanced concentrations", EUR-17625.

6.3.1 Natural radionuclides

Of all the natural radionuclides in the earth's crust, those found to be the main sources of human radiation exposure are ^{40}K (potassium-40), ^{232}Th (thorium-232), ^{235}U (uranium-235) and ^{238}U (uranium-238). Potassium especially occurs widely in nature, and the radioactive isotope ^{40}K makes up 0.012 % of the natural elemental form.

The decay of the three heavy radionuclides (^{232}Th, ^{235}U and ^{238}U) results in daughter products that are also radioactive; these radionuclides in turn decay, and the process continues down chains of radionuclides of several different elements (decay series), until eventually a stable isotope of lead results. One of the most important daughter nuclides is radium-226, which is found in the uranium-238 decay series. It is soluble in water and chemically very different from uranium. The decay of ^{226}Ra results in ^{222}Rn (radon-222), an inert gas that can escape via gaseous pathways. The radionuclides ^{210}Pb and

^{210}Po (^{238}U decay series) can occur in compounds that are volatile at high temperatures (several hundred degrees Celsius), raising the possibility of dispersion via airborne routes.

Certain human activities increase man's exposure to naturally occurring radionuclides. The two principal groups of activities are:

- mining or extraction of material containing high concentrations of natural radioactivity;
- processing of material containing natural radioactivity such that enhanced concentrations occur in products, by-products or wastes.

However, it is important to realise that the large majority of the general public's exposure to man-made radiation occurs from medical treatment.

6.3.2 Current Legislation and Systems of Radiological Protection

The actual regulations applying to practices involving exposure to materials containing high concentrations of natural radioactivity show considerable variation across the EU Member States, and are, in general, less restrictive than regulations applicable to man-made radionuclides. However, the subject has received more attention in recent years, and this has resulted in a more consistent approach towards dealing with the avoidable risks posed by radiation from all sources, as demonstrated in ICRP-60 and the EU Directive 96/29/EURATOM.

Reporting levels are listed in Annex I of the Directive. Thus a practice may be exempted from reporting requirements if it only involves materials with radionuclide concentrations not exceeding the various exemption values.

The specific provisions in Title VII of the Directive imply that only those work activities need be considered that lead to a significant increase in the exposure of workers or members of the public. It is left to the competent national authorities to decide which industries warrant closer attention, though the justification for regulatory control has to be judged in the context of each particular industry, by considering the effect of regulation both on its radiological impact and the benefits of the practice.

6.3.3 Processes leading to arisings of waste containing enhanced concentrations of natural radionuclides

The presence of ^{238}U and ^{232}Th in coal gives rise to activity levels generally in the range 0.03 to 0.05 Bq/g, but higher levels have been recorded in coal from particular sources. In the ash from combustion of coal, radioactive concentrations are enhanced by about a factor of 10 for most radionuclides, but by a factor of 100 for ^{210}Po and ^{210}Pb. Various assessments of the radiological impact of coal ash have been undertaken that show the risk to workers and also to the public is low. Similarly, the radiological impact of radioactive emissions from power station stacks has been shown to be low.

On the basis of limited data, the impacts of other fossil fuels such as oil, gas and peat are likely to be less than for coal.

The concentrations of natural radioactivity in phosphate ore vary from roughly 0.1 to 5 Bq/g and are dominated by the contribution from the ^{238}U series. However, as a result of the chemical process the fertiliser product contains uranium concentrations approximately 50% higher than in the ore, and most of the radium is left in the phosphogypsum waste. One problem area concerns the re-use of this phosphogypsum waste in the manufacture of building materials and the effectiveness of the associated regulatory controls.

Oil and gas production give rise to scales and sludges containing naturally occurring radioactive materials with activities of the order of 100 Bq/g. Total arisings of these waste materials in the European Union amount to a few thousand cubic metres per year. Assessments of the radiological impact of the scales and sludges generally indicate doses to individual workers of around 1 mSv/a. The radiological impact on the public of disposal of scale material is not well documented. The eventual disposal of off-shore structures is an issue that requires further attention.

Naturally occurring radioactivity levels in rare earths and zirconium ores and in associated products and wastes are generally around 10 Bq/g. Occupational exposures during the processing of these materials have been conservatively estimated to be in the region of a few mSv/a, mainly from internal exposure. The dose to the public from liquid and airborne effluents from the processes have been shown to be low, though the estimated doses resulting from landfill disposal of the waste materials are more significant. Subsequent redevelopments at landfill sites could give rise to individual doses of about 0.1 mSv/a. Assessments of the collective dose over the very long-term from landfill disposal of the wastes range up to 10^5 man-Sv.

Radionuclide concentrations in iron ore are generally low, even in the slags and other wastes. Higher levels occur in aluminium, tin and titanium ores in both raw materials and wastes. Very high radionuclide concentrations occur in pyrochlore, the source of niobium, and this is reflected in the products and the wastes. Assessments of the radiological impact of operations associated with metal smelting generally indicate that worker doses are low, with the exception of those from pyrochlore where values of up to a few mSv/a are possible. Exposure of the public owing to releases from these processes is generally assessed to be low. However, the potential doses from landfill disposal of waste could be more significant, where values up to 10 mSv/a could occur as a result of intrusion and site redevelopment.

Within the European Union, the problem of management of tailings from copper mining is confined to the Mansfeld region of the former GDR, where copper mining and smelting was undertaken from the Middle Ages up to the mid 20^{th}-century. This has left a legacy of about 110 million cubic metres of waste in over 1000 waste piles. The levels of natural radioactivity in the waste range from hundreds to thousands of Bq/kg.

A number of waste materials containing enhanced levels of radioactivity are used in the manufacture of building materials. Probably the most significant of these is phosphogypsum, which is used in place of natural gypsum in various building products. Less widespread, but also of radiological significance, is the use of mining wastes and slags, particularly in Germany. Assessments of occupational exposure during the manufacture of building materials using recycled waste suggest that, even with conservative assumptions, individual doses are only a few mSv/a at most. Studies have shown that a member of the public typically receives an external body dose of only about 0.6 mSv/a as a result of time spent indoors or in the vicinity of buildings if the building materials do not contain enhanced levels of radioactivity. Thus there is considerable margin for increases in external exposure resulting from use of the recycled materials, though probably of greater importance in most cases would be the increased internal dose from radon, but on this point current data are inconsistent.

As mentioned above, uranium milling activities produce a special category of waste materials called tailings that contain very low concentrations of natural radionuclides, some of which are long-lived. Uranium mining and milling activities in the European Union are relatively limited and are confined to France, Spain, Portugal and Germany.

The chemical industry is very diverse and involves a great number of different types of raw material, and there is a general lack of accurate information on the radionuclide content of these materials and the resulting chemical products. Varying radionuclide concentrations are likely to exist in at least some of the raw materials.

7. Interaction with the Public and Social Issues

7.1 Public perception of the nuclear industry

The public's perception of the nuclear industry is inextricably linked to its perception of radioactive waste management to the extent that the latter has now a major influence on the former. In addition, most - if not all - forms of waste disposal raise controversy, but the issue of radioactive waste disposal, in particular, causes considerable anxiety in many areas of the world.

The factors influencing the public's perception of the nuclear industry and of radioactive waste management are often difficult to define and an analysis of these is beyond the scope of this report. However, what is clear is that past accidents at a number of nuclear plants have led to a majority of the public feeling uneasy about the industry, and even minor incidents now accentuate the problem of diminishing public confidence. Reports of increased numbers of leukaemia cases in areas surrounding some nuclear installations provoke great concern amongst the general public, in spite of independent investigations which conclude that there is no proof of a link between reports of higher doses of radiation in these areas and the incidence of leukaemia.

The accident at Three Mile Island in March 1979 had a marked impact on the public's opinion of nuclear power and the accident at Chernobyl in April 1986 was a further blow to the nuclear industry's public image.

The public's perception of the detrimental environmental aspects of nuclear power is not offset by an appreciation of its beneficial effects, notably the replacement of fossil fuel burning in electricity generation. With regard to radioactive waste, the public is generally unaware that the actual quantities produced are extremely small in comparison with the amounts of hazardous waste produced by other industries. There is also a lack of awareness of the technologies available for managing nuclear waste.

It is very difficult to generalise about the public's perception of the nuclear industry and radioactive waste management in the European Union as this varies considerably from one Member State to another.

In Ireland, for example, the Three Mile Island accident turned the Irish public very much against the proposal to build a nuclear power reactor at Carnsore in County Wexford. Following the Chernobyl accident, the public's anti-nuclear stance hardened with opposition to nuclear programmes in other countries as well.

In Sweden, just one week after the accident at Three Mile Island, Swedish political parties ordered a referendum, the result of which committed Parliament to phasing out nuclear power. However, recent opinion polls in Sweden show that a majority of the public are now in favour of keeping the present reactors in operation for the remainder of their design lifetime, though Parliament is still bound by the result of the earlier referendum to phase out nuclear power production by 2010. On the other hand, a site for a repository for high-level waste has not yet been selected and the local population at some potential sites have not been in favour of a repository in their area.

A referendum in Italy held after the accident at Chernobyl resulted in a moratorium on all nuclear development.

Overall public feeling in the Netherlands is for a passive acceptance of the nuclear industry as a whole, provided there are currently no issues being discussed that could adversely effect the industry's image, for example licensing or waste management problems.

In Finland, two nuclear power plants were selected in the early 1980s as sites for low and intermediate level waste repositories; this provoked no particular concern amongst the local population, and the disposal projects were subsequently successfully implemented.

According to an annual public opinion poll in France, public support for the nuclear industry as a whole has increased, especially among students and teachers. However, French attitudes towards radioactive waste disposal in particular are notably more sceptical. More than two-thirds of the people questioned believed that they were not adequately informed about nuclear issues.

7.2 Public involvement in the site selection procedure

The disposal of radioactive waste is of particular concern to the public, especially when potential underground repositories are mentioned. This concern probably stems from the time before any public involvement in the site selection process.

Some Member States have developed procedures for establishing prospective waste disposal and storage sites that involve the public in the decision-making process. These procedures vary somewhat between countries, though they all play an integral part in gaining the public's confidence and acceptance. There is a general consensus, at least in the Member States of the European Union, that the public should be involved at the local rather than at the national level in decisions on siting and licensing.

7.2.1 Belgium

Upon request from the Government, ONDRAF/NIRAS has prepared a report that takes stock of the studies that have been and are in the process of being carried out on the subject of the different options available for the long-term management of low-level radioactive waste. This request stems from the government policy statement of June 1995, in which the Government expressed its wish that in 1997 a choice would be made between the technical alternatives for the long-term management of low-level and short-life radioactive waste on the basis of a report on the alternatives. In this report, submitted to the Government in June 1997, ONDRAF/NIRAS set out the different alternatives for the long-term management of such radioactive waste and compared them in relation to their safety and associated costs.

In December 1996 the Ministry of Economic Affairs also put ONDRAF/NIRAS in charge of making an initial assessment of 26 military sites, the use of which is being changed, with a view to possibly later using these sites within the framework of the ONDRAF/NIRAS activities. A discussion of the problems of using these military sites as an interim solution to long-term *storage* will be integrated in the report on the different options. The report also considers the permanent waste management solutions of near-surface and deep disposal.

- *Long-term storage:* This involves storing waste in storage sites, the life of which may be as much as a hundred years.

- *Near surface disposal:* In April 1994 ONDRAF/NIRAS published a report on the technical feasibility in Belgium of surface disposal of low-level radioactive waste and waste containing radionuclides with a short half-life. Surface disposal consists of storing the drums in concrete modules that are shielded by a number of water-tight layers so that they are impermeable to rainwater. The location of the disposal is determined by the nature of the subsoil, which offers an additional natural protective layer. Such disposal must guarantee the protection of the population and the environment for 200 to 300 years, after which the site may be released. After a period of 200 to 300 years the radioactivity of this waste will have reduced through natural decay to a safe level equivalent to that from natural background activity. In the April 1994 report, 98 potentially favourable zones were identified based on a bibliographical study of their geology. A general outcry followed, with all the municipalities involved issuing council motions refusing further investigations. As a result, a study was undertaken in order to identify the social effects of radioactive waste disposal, and a proposal was made which could possibly resolve the social associated problems. The project involved the analysis of known social effects and various case studies, but results have so far been unsuccessful.

- *Deep disposal:* This consists of storing the radioactive waste in an infrastructure that is built in a deep-lying, virtually non-porous clay layer that has remained stable for millions of years. Such a clay layer gives sufficient protection even in the case of very long-life radioactive waste.

7.2.2 Finland

The site selection process for spent fuel disposal is underway and currently the investigations are carried out at four candidate sites, two of them being nuclear power plant sites. There are local opponent groups at those sites but they have not tried to stop the investigations. The consent of the council of the host municipality is required for eventual site selection, scheduled to occur in the year 2000. Before this, an environmental impact assessment process, enabling participation of the local public in the site selection process, will be carried out. Both the project developer and the regulator have significant roles in the process.

Opinion polls have been carried out to determine the attitudes of the citizens of municipalities subject to site investigations. These polls indicate that people living in the power plant municipalities are significantly more in favour of spent fuel disposal than those living in municipalities with no nuclear activities. According to the opinion polls of 1997, 60-65% of the people living in the host municipalities of the Olkiluoto and Loviisa power plants would accept safe disposal of spent fuel in their community, whereas the respective percentage is 30-45% in the two candidate municipalities having no nuclear activities. Opinion polls and interviews also indicate that the public perceives regulators and independent scientists to be the most reliable source of information, while the trust of proponents, environmentalists, journalists and politicians is substantially lower.

7.2.3 France

A full public inquiry must be held before the Government can approve an application for the building of a waste site. This inquiry gives the public the chance to voice their opinions and to learn about the environmental impact of such a site.

The site selection process currently in progress concerns the selection of suitable sites for the construction of underground research laboratories. This procedure was established by the law of December 1991, and requires the involvement of Parliament, local government, organisations and the public. As a consequence of the application of this law, the Government appointed a negotiator whose task was to determine potential sites from amongst the volunteer local communities. As a result, four sites were approved by the Government for further study, and after two years of surface and subsurface surveys it was confirmed that three sites would be suitable (two sites had been merged). In May 1996, ANDRA were authorised by the Government to submit applications for the construction and operation of underground research laboratories, and on the basis of these applications public enquiries, hearings and local votes were conducted at the three sites concerned. Results appear positive, and the final decision of the Government is expected shortly.

7.2.4 Germany

Information on a selected site is presented to both the State and Federal Parliaments, as well as to the local organisations, such as the Farmer's Association, etc. The same information is also printed in local newspapers and leaflets. An application, safety report and full description must be on public display near the proposed site. Thereafter, a public inquiry is arranged by the licensing authority, enabling concerned groups and individuals to present their case.

7.2.5 *Spain*

No formal procedure exists is Spain, although the Government monitors public attitudes when reaching a decision. Around the El Cabril site, information to the public was provided via communications involving institutions such as the Town Council. These institutions have highlighted the social, economic and environmental benefits, and also made proposals for improvement in infrastructure. At present, a Commission of the Spanish Senate is studying the problem of radioactive waste management in Spain with a view to examining possible legal initiatives.

7.2.6 *Sweden*

In Sweden, SKB's aim is to carry out siting and construction of the required facilities in consensus with the concerned municipalities and local populations. The work of carrying out an environmental impact assessment (EIA) in an open and broad process occupies a central role in this context.

Since the 1970s, SKB has conducted extensive studies on the geological conditions deep within the bedrock. Furthermore, a number of safety assessments for deep repositories have also been performed over the years. Based on these results and experiences, SKB began the actual job of siting the deep repository for spent nuclear fuel in 1992. The work is now underway and a great deal of information has so far been gathered.

7.2.7 *United Kingdom*

Within the UK, responsibility for repository site selection rests with the repository developer. For instance, in the case of the proposed LILW repository, this responsibility rests with UK Nirex Ltd. Government policy is that the site selection process must be practicable and cost-effective to implement, that it should provide reasonable reassurance that the selected site would meet the requisite level of public safety and that the process should provide public confidence that the selection process had been based on a rational approach under UK regulatory processes, which provide for extensive consultation, public enquiries etc. The developer is required to prove that these conditions for site selection have been satisfied.

7.3 Nuclear protests

There are an increasing number of public protests against many new construction projects in certain Member States. These protests range from opposition to the building of new roads and airports, to opposition to the building of radioactive waste repositories and the transportation of radioactive waste. However, it is noted that there has ***never*** been an accident involving the transportation of radioactive waste that has resulted in detrimental environmental effects.

There have been numerous public protests in Germany recently. For example, in February 1997, anti-nuclear activists in Bonn chained themselves to a freight train carrying radioactive waste (heading for

Dounreay) in order to highlight the potential dangers of transporting such materials - just days before, a German train carrying irradiated fuel had derailed in France. The German activists have been known to sabotage railway lines, use bomb threats and hold sit-down demonstrations on railway tracks, all in an attempt to stop radioactive waste shipments.

Anti-nuclear activists have been accused of forging company information leaflets in an attempt to provoke public anxiety ahead of a planned shipment by RWE of nuclear waste materials. RWE has issued a statement disassociating itself from the leaflets, which make false allegations about company policy and the role of the German military in the event of a nuclear emergency.

Anti-nuclear activists have recently been suspected of sabotaging a stretch of high-speed rail track in southern Germany. Two trains smashed into grappling hooks thrown on to the overhead cables between Stuttgart and Mannheim, blocking the line for several hours.

Environmentalist organisations, such as Friends of the Earth, were opposed to the proposal for an underground repository near Sellafield (UK), among other places, because of fears that it may lead to radioactive leaks into the Irish Sea. Irish protesters and UK fishermen are also now pushing for zero radioactive discharge from Sellafield after data revealed increases in radioactive contamination of fish and shellfish.

Activists are not only opposed to radioactive waste, but also other aspects of the industry. They have recently staged a protest at the Krümmel nuclear power plant near Hamburg. The protest lasted for more than a week and involved blocking a railway track near the power station in order to prevent the transportation of spent fuel bound for reprocessing at Sellafield.

There are also some pro-nuclear organisations, which usually involve workers from the nuclear industry. These organisations, such as the World Council of Nuclear Workers in France and the European NucWorker (TEN), stage marathons and bicycle tours in an effort to heighten public awareness of the nuclear industry as a whole.

7.4 Public information

Interaction with the public is a relatively recent development. There are now various information sources available to the public, for example:

- visitor centres at various sites;
- brochures and other printed matter;
- the Internet;
- educational packages at certain schools.

It is in the interest of both the public and the nuclear industry to ensure that an open and frank dialogue with a wide variety of organisations and the media is maintained and that the public themselves are kept fully informed on all nuclear issues, including radioactive waste management.

Information on individual initiatives has been provided by certain Member Sates.

7.4.1 Belgium

Various printed matter is available to the public as well as a permanent visitor information centre targeted at school children and an interactive mobile information centre targeting the public at large.

7.4.2 Denmark

Risø National Laboratory publishes an annual report describing international developments in the field of nuclear energy; part of this report is devoted to waste management.

7.4.3 Finland

The implementing organisation for spent fuel disposal, Posiva Oy, runs a communication programme that includes a variety of activities aimed at different target groups. Press conferences, contact group meetings with municipality representatives, open houses for the public, exhibitions, lectures to different groups, visits to drilling sites, newspaper advertising, as well as the use of a variety of written materials, are included in the programme. Existing nuclear waste facilities offer an excellent possibility for educating the general public but, for practical reasons, such sites can be shown to only a small number of people.

7.4.4 France

ANDRA, the national radioactive waste agency, is actively involved in providing information to the public. As required by the law of December 1991, ANDRA publishes every year a register listing the location and condition of all radioactive waste on French territory. This inventory is available on request free of charge to members of the public, administrations and so on.

7.4.5 Germany

Guided tours are available through the mine at the Morsleben and Konrad sites, and basic information is provided to the public in the form of leaflets and public information brochures in particular. A number of meetings are also organised in order to inform various social groups. There is also a permanent public information centre near to the Gorleben site

7.4.6 Ireland

The Radiological Protection Institute of Ireland publishes an annual report that is available to the public.

7.4.7 Netherlands

The COVRA facility includes an office building and an exhibition centre that are integrated into the fence system around the controlled area. COVRA's philosophy with respect to public information is to encourage people actually to visit to the facilities. Ease of accessibility by visitors has therefore been taken into account in the design of all buildings. To enter the controlled area, a simple administrative procedure has to be followed; guidance by a COVRA employee is obligatory. There are approximately 500 visitors to the site per year.

7.4.8 Portugal

Information on radiological protection and radioactive waste management activities is made available to the public in a booklet on the environment in Portugal, published annually by the General Directorate for the Environment.

7.4.9 Spain

ENRESA has devoted a great deal of time and effort to public communication and information, with the aim of informing them of the company's role as a public service. In this context, two visitor centres are available, one at El Cabril disposal centre, and the other at ENRESA's Madrid headquarters. They each receive some eleven thousand visitors every year. Construction of a third visitor centre, associated with the dismantling activities at Vandellos I NPP, is now under way.

There are several regular publications, such as the Estratos and Sierra Albarrana, which report on ENRESA's activities. Brochures and videos have also been produced.

Courses and seminars on radioactive waste management are also provided and are mainly directed at local primary school teachers and journalists.

7.4.10 Sweden

SKB holds periodic exhibitions and trade fairs, and representatives of the company make regular visits to schools as part of their public information campaign. The ship used in the transport of radioactive waste serves as a floating exhibition hall, and the public can also visit SKB's mobile exhibition centre and permanent information facilities.

SKB now also has its own Internet address and has produced a CD-ROM that provides current information about the nuclear industry as a whole and strategies for radioactive waste disposal.

7.4.11 United Kingdom

BNFL, the UK's largest radioactive waste processing company has set up an interactive visitor centre at its Sellafield site that attracts large numbers of the public every year. BNFL also operates a mobile information centre. UK

Nirex Ltd., the UK's ILW repository developers, have also initiated an educational package for teachers which is aimed at the 11-17 age group. Numerous glossy brochures, newsletters, and video productions have also been made available for these organisations. Visitor centres are also maintained by other nuclear operators, in particular by Nuclear Electric, Scottish electric, Magnox Electric and UKAEA Dounreay.

8. TABLES

TABLE A: NUCLEAR POWER PROGRAMMES IN THE EU MEMBER STATES

Country[1]	Net[2] power installed at end of year (GWe) (of power stations in operation or committed)					
	1995	2000	2005	2010	2015	2020
Belgium	5.8	5.8	5.8	5.8	5.8	4.7
Finland	2.3	2.5	2.5	2.5	2.5	2.5
France	59	62	67.3	67.3	67.3	67.3
Germany	21.1	21.1	21.1	21.1	21.1	21.1
Italy	Moratorium on operation of nuclear power plants					
The Netherlands	0.5	0.5	0	0	0	0
Spain	7.1	7.5	No official plan beyond the year 2000			
Sweden[3]	10	10	10	10	0	0
United Kingdom	14.1	12.0	9.3	7.0	3.7	1.2

1 Only Member States with a nuclear power programme included.

2 Gross capacity is roughly 4% higher than net.

3 The implementation of a parliamentary decision to phase out nuclear energy by 2010 is now being debated and discussed among the political parties.

TABLE B: WASTE IN INTERIM STORAGE AT END 1994

Country	Quantities of waste in interim storage[1] (in m^3 unless otherwise stated)			
	LILW – surf	LILW - deep	HLW or SFuDD	Notes
Austria	1,400	-	-	7020 drums of 220 litre (cemented)
Belgium	9,255	3,355	195	
Denmark	1,000	100*	0.2 tU (~ 0.03 m^3)	*some may later be classified for surface disposal
Finland	3,000	-	1,480*	*800 tU of spent fuel
France	none	80,000	1,500	
Germany	not applicable	91,300	1,620[2]	no surface disposal in Germany
Greece	170	none	none	
Ireland	none	none	none	small quantities stored on-site by user
Italy	23,000		18 m^3 and 330 tU*	*HLW in m^3, spent fuel in tU
Luxembourg	0.5	none	none	no conditioning facilities
The Netherlands	6,000	none	none	
Portugal	60	10	none	
Spain	17,000	Mainly from decommissioning and reprocessing	2,500*	*1,650 tU of spent fuel
Sweden	14,200	800	5,550*	*3,000 tU of spent fuel
United Kingdom	4,180[3]	66,100	650	

1 Volumes are of waste conditioned for disposal assuming most probable conditioning method.

2 Heat generating waste and spent fuel.

3 Equates to LLW waste scheduled for disposal in the Drigg and Dounreay surface disposal sites as of 1/4/94.

TABLE C: WASTE DISPOSED OF UP TO END 1994

Country[1]	Quantity[2] (m^3)	Type of disposal	Site	Period considered
Belgium	15,000	ocean disposal	North Atlantic	
Finland	1,700	rock cavity	Olkiluoto	1992-1994
France	9,900 525,000 100,000	ocean disposal near surface near surface	North Atlantic Centre de la Manche Centre de l'Aube	1967 and 1969 1969-1994 1992-1994
Germany	96 16,150 14,500[3] 1,364	ocean disposal deep disposal deep disposal deep disposal	North Atlantic Asse Morsleben Morsleben	1967 1967-1978 1971-1991 1994[4]
Italy	23	ocean disposal	North Atlantic	1967
The Netherlands	8700	ocean disposal	North Atlantic	ceased in 1982
Spain	2,900	near-surface	El Cabril	1992-1994
Sweden	15,482 2,462 2,000 2,205 325	near surface surface surface surface surface	SFR OKG Ringhals Forsmark Studsvik	1988-1994 1986-1994 1989-1994 1988-1994 1988-1994
United Kingdom	26,000 880,000 15,000	ocean disposal shallow burial shallow burial	North Atlantic Drigg Dounreay	ceased 1983 up to 1994 up to 1994

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1 Austria, Denmark, Greece, Ireland, Luxembourg and Portugal have not practised disposal.

2 Volumes presented here include conditioning products and host package.

3 Includes about 6,700 spent sealed radiation sources.

4 No waste emplacement from February 1991 through January 1994 owing to legal proceedings.

TABLE D: ESTIMATED ARISINGS OF LOW- AND INTERMEDIATE-LEVEL WASTE DESTINED FOR SURFACE OR NEAR-SURFACE DISPOSAL (LILW - SURF) IN THE EU MEMBER STATES (1995-2019)

Country	Quantities of waste arising during period (m^3)[1]					Notes
	1995-1999	2000-2004	2005-2009	2010-2014	2014-2019	
Austria	330	300	300	300	300	300 drums of 220 litre annually; cemented
Belgium	2,532	2,274	2,326	2,167	2,474	
Denmark	100	100	100	50	50	
Finland	1,500	1,500	1,500	1,500	1,500	near-surface disposal
France	86,000	64,500	64,500	64,500	64,500	quantities delivered
Germany	-	-	-	-	-	no LILW-surf in Germany
Greece	70	70	~ tens	~ tens	~ tens	
Ireland	5	5	10	No forecast	no forecast	
Italy	1,500	1,300	no forecast	no forecast	no forecast	mainly from decommissioning
Luxembourg	0.5	0.5	<0.5	<0.5	<0.5	
The Netherlands	-	-	-	-	-	no LILW-surf in The Netherlands
Portugal	25	30	30	35	35	
Spain	10,500	10,000	5,500	9,000	15,500	
Sweden	5,400	5,400	5,400	70,000	70,000	
United Kingdom	58,000	52,000	52,000	46,000	46,000	

1 Volumes are of waste conditioned for disposal assuming most probable conditioning method.

TABLE E: ESTIMATED ARISINGS OF LOW- AND INTERMEDIATE-LEVEL WASTE DESTINED FOR DEEP GEOLOGICAL DISPOSAL (LILW - DEEP) IN THE EU MEMBER STATES (1995-2019)

Country	Quantities of waste arising during period (m³)[1]					Notes
	1995-1999	2000-2004	2005-2009	2010-2014	2015-2019	
Austria	none	None	none	none	none	
Belgium	602	745	808	445	239	
Denmark	5	5	none	none	none	
Finland	none	None	none	none	none	
France	14,000	2,500	2,500	2,500	2,500	new compacting installations in use by 2000
Germany	37,800	55,000	24,100	20,600	13,000	
Greece	none	None	none	no forecast	no forecast	
Ireland	none	None	none	no forecast	no forecast	
Italy	200	None	no forecast	no forecast	no forecast	from decommissioning
Luxembourg	none	None	none	none	none	
The Netherlands	2,000	2,000	2,000	2,000	2,000	
Portugal	2	2	2	2	2	
Spain	This type of waste will arise mainly from decommissioning of NPP's and reprocessing of spent fuel from Vandellos I NPP. Volume estimates are not currently available.					
Sweden	268	268	1,910	3,820	3,820	
United Kingdom	23,000	22,000	22,000	6,500	6,500	

1 Volumes are of waste conditioned for disposal assuming most probable conditioning method.

TABLE F: ESTIMATED ARISINGS OF HIGH-LEVEL WASTE/ SPENT FUEL DESTINED FOR DIRECT DISPOSAL IN THE EU MEMBER STATES (1995-2019)

Country[1]	Quantities[2] of waste arising during period in m³ unless otherwise stated					Notes
	1995-1999	2000-2004	2005-2009	2010-2014	2015-2019	
Belgium	40	35	44	73	73	Figures are based on reprocessing, but this is no longer the reference solution for spent fuel.
Finland	350	370	370	370	370	
France	700	700	700	700	700	m³ of glass
Germany	264	399				only vitrified wastes returned from France & UK after reprocessing of 5500tU of spent fuel; see Table G for total amounts of spent fuel.
Italy	0	23	0	no forecast	no forecast	
The Netherlands	0	20	20	20	0	
Spain	790 tU	770 tU	810 tU	40 m³+ 780 tU	710 tU	vitrified wastes returned from France (m³), and spent fuel destined for direct disposal (tU)
Sweden	1,060 tU	1,060 tU	1,060 tU	1,200 tU	-	
United Kingdom	350	220	220	3		

1 Austria, Denmark, Greece, Ireland, Luxembourg and Portugal have no arisings; spent fuel from research reactors is returned to supplier.

2 Volumes presented here assume all waste in form conditioned for disposal assuming most probable conditioning method. Separate figures are presented for vitrified waste (in m³) and spent fuel destined for direct disposal (in tU). For UK and France, the time at which HLW arises is taken as the time of vitrification. For countries sending spent fuel to UK and F for reprocessing, the time of arising is taken as the time at which the vitrified waste is expected to be returned to the country of its production. For countries considering direct disposal of spent fuel, the time of arising is taken as the time at which the spent fuel is conditioned.

TABLE G: SPENT FUEL DISCHARGED IN THE EU MEMBER STATES UP TO END 2019

Country	Reactor type[1]	Quantity of fuel discharged per indicated period[2] (tonnes heavy metal)					
		to end 1994	1995-1999	2000-2004	2005-2009	2010-2014	2015-2019
Austria	-						
Belgium	PWR	1,250	600	600	550	500	500
Denmark	MTR	6.3	0.6	0.6	0.6	0.6	0.6
Finland[3]	LWR	1,070	350	370	370	370	370
France	LWR GGR FBR	10,000 6,190 65	5,000 – 30	4,500 – 30	4,500 - -	4,000 - -	4,000 2,250 -
Germany[4]	LWR	5,000	2,400	2,400	2,400	2,400	2,400
Greece	RR	0.017	0.007	0.020	0.020	no forecast	no forecast
Ireland	-						
Italy	LWR GCR	375 1,426	102	0	0	0	0
The Netherlands	LWR RR	240 no data available	33 0.2	33 0.1	30 0.1	- 0.1	- 0.1

1 PWR: pressurised water reactor
LWR: light water reactor
GGR: gas-cooled graphite-moderated reactor
AGR: advanced gas-cooled reactor
GCR: gas-cooled reactor
BWR: boiling water reactor
MTR: materials test reactor
RR: research reactor
FBR: fast-breeder reactor

2 Quantities presented here include spent fuel destined for direct disposal, spent fuel which has already been reprocessed and spent fuel for which the intention is to reprocess.

3 For the spent fuel disposal concept envisaged in Finland, one tonne of heavy metal corresponds to about 1.85 m³ of waste canister volume.

4 Small amounts of spent fuel also expected from pebble bed reactors (305 casks Castor THTR/AVR, 90 casks Castor AVR), material test reactors, research reactors, prototype reactors.

Country	Reactor type[1]	Quantity of fuel discharged per indicated period[2] (tonnes heavy metal)					
		to end 1994	1995-1999	2000-2004	2005-2009	2010-2014	2015-2019
Portugal	RR	0.03					
Spain	LWR	1,650	790	770	810	780	710
Sweden	BWR PWR	2,329 673	790 270	790 270	790 270	900 300	
United Kingdom[5]	GGR AGR LWR		4,000 1,200 150	2,300 1,200 150	- 750 150	- 750 150	- 750 150

5 Quantities are estimated using values from Third Report since more recent data are not available.

TABLE H: EXECUTIVE BODIES RESPONSIBLE FOR ALL OR PART OF RADIOACTIVE WASTE MANAGEMENT IN EU MEMBER STATES

Country	Radioactive Waste Management Agency	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
Austria	The Ministry of Health and Environment has designated the Austrian Research Center Seibersdorf to manage and store radioactive waste.							
Belgium	ONDRAF/NIRAS public set up in 1980-81	in parallel with the industrial operators	*	*	*	*	*	*
Denmark	Risø national laboratory, by agreement with the National Institute of Radiation Hygiene, is responsible for collecting and storing radioactive waste from research laboratories, hospitals and industry. The national regulatory authorities are: The Inspectorate for Nuclear Installations under the Emergency Management Agency and the National Institute of Radiation Hygiene under the National Health Services of Denmark.							
Finland	Spent fuel disposal: POSIVA other: Industry	*	STUK sets general criteria and industry defines the specifications	*	*	*	*	STUK for small producer waste
France	ANDRA public set up on 7/11/79	Responsibility of the industry	*	*	*	*	* (partially)	

Country	Radioactive Waste Management Agency	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
Germany	BfS Federal body responsible for engineered storage and disposal of radioactive waste	Waste producers	BfS for disposal Supervising authorities of the federal states for interim storage	BfS in co-operation with supervising authorities for disposal supervising authorities for interim storage	* (DBE acts on behalf of BfS)	BfS for disposal waste producers for waste management strategies (e.g. conditioning, transportation, interim storage)	Performed by the waste producers after permit from BfS or other competent authorities	by the waste producers and/or collecting depots (Landessammelstellen) after permit from BfS or other competent authorities
Greece	The management and storage are the task of the ministries concerned in co-operation with the Atomic Energy Commission and the Demokritos Research Centre.							
Ireland	The Radiological Protection Institute of Ireland is responsible for the regulation of the storage, transport and disposal of radioactive waste arising from the use of radioisotopes in accordance with Statutory Instruments 43/91 and 151/93.							
Italy	NUCLECO semi-public set up in 1981	waste producers (ENEA & ENEL) and NUCLECO	ANPA (National Agency for the Environmental Protection)	ANPA	ENEA NUCLECO	ENEA	Commercial operators (under ANPA-control)	* (for waste from medical, industrial and research activities)
Luxembourg	The Radiological Protection Department of the Ministry of Health is responsible for the regulation, transport and the management of interim storage of radioactive waste arising from spent sources.							
The Netherlands	COVRA private set up in Dec. 1982	* and waste producer	*	*	*	*	*	*

Country	Radioactive Waste Management Agency	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
Portugal	The Department of Radiological Protection and Safety of the General Directorate for the Environment is responsible for the collection, treatment and storage of radioactive waste from research laboratories, hospitals and industry. The national responsible authorities are the General Directorate for the Environment of the Ministry of Environment and the General Directorate for Health of the Ministry of Health.							
Spain	ENRESA public set up in 1984	waste producers	*	*	*	*	*	*
Sweden	SKB private set up in 1972	industry for LILW-near surface SKB for LILW-deep + spent fuel	SKI + SSI	*	*	*	*	*
United Kingdom	BNFL for Drigg UKAEA for Dounreay Nirex for proposed ILW repository	waste producers	* subject to regulatory requirements	*	* subject to regulatory requirements	waste producers and UK Government	Waste producers subject to regulatory requirements	BNFL, UKAEA, British Energy, Magnox Electric

* **responsibility of the waste management agency**

TABLE J: INTERIM STORAGE FACILITIES FOR VITRIFIED HIGH-LEVEL WASTE (HLW) IN THE EU MEMBER STATES

Country	Facility/site	Interim storage capacity in m^3	Planned period of operation
Belgium	Building 36 of Belgoprocess, Dessel	108	1997-
Finland	none		
France	La Hague, Marcoule	3,850	
Germany	Brennelementlager Gorleben (BLG)	420 x 28 HLW canisters	1995-2035
Italy	none		
The Netherlands	storage vault COVRA at Borssele (start of construction 1997)	70	2001-2015
Spain	to be defined at end of century		≥ 2010
Sweden	none		
United Kingdom	Sellafield Vitrified Product Store	1,200	

TABLE K: INTERIM STORAGE FACILITIES FOR SPENT FUEL

Country	Facility/Site	Capacity[1] (tonne heavy metal)	Period of operation
Belgium	Doel - reactor pool Doel - AFR 1st module Doel - AFR 2nd & 3rd modules Tihange - reactor pool Tihange - AFR wet pool	628 600 1,130 680 650/1,750	1994 - 1995 - 1998 - 1994 - mid-1997 -
Finland	Olkiluoto/Loviisa	2,300	Loviisa: 1978 extension: 1985 Olkiluoto: 1981 extension: 1987
France	La Hague, Cadarache	20,400	
Germany	centralised facilities: Ahaus-BZA Gorleben-BLG Jülich Greifswald-ZAB Greifswald-ZLN nuclear power plants	 1,500 +2,700 applied for 3,800 158 casks type Castor THTR/AVR 740 620 applied for 4,400 +460 applied for	 1992 - 1995 - 1993 - 1986 - 1997/98 -
Italy	nuclear power plants + AVOGADRO	610	
The Netherlands	Borssele	50	1971-2004
Spain[2]	J Cabrera Garoña Almaraz 1 Almaraz 2 Ascó 1 Ascó 2 Cofrentes Vandellos 2 Trillo	64 (127) 236 (392) 760 760 583 583 446 (728) 663 294	1998- 1998- 1994- 1994- 1994- 1994- 1998- 1996- 1996-
Sweden	CLAB	5,000[3]	
United Kingdom		9,000 nominal	

1 The stated capacity includes that available in reactor pools less an allowance for the storage of one complete reactor load.

2 Capacities as of 31/12/96; ( ) = capacities at the end of the re-racking operation; allowance for the storage of one complete reactor core.

3 To be expanded to 7,800, which equals the predicted amount from operation up to 2010.

TABLE L: SUMMARY OF PRESENT AND PLANNED DISPOSAL FACILITIES FOR LOW- AND INTERMEDIATE-LEVEL WASTE (LILW) IN THE EU MEMBER STATES

Country[1]	Waste Type	Facility/site	Capacity (m^3)	Period of operation
Belgium	LILW-surf	to be decided	100,000	to be decided
Finland	LILW-surf LILW-surf	VLJ-repository LOSI-repository	8,500 5,600	1992- 1998-
France	LILW-surf LILW-surf	Centre de la Manche Centre de l'Aube	500,000 1,000,000	1969-1994 1992-
Germany	LILW-deep LILW-deep LILW-deep	Morsleben Konrad Gorleben	40,000[2] up to 650,000 up to 1,100,000[3]	Jan 94 - June 2000 at least 40 years at least 70 years
Italy	long-term storage is foreseen			
The Netherlands	long-term (100 years) above ground interim storage is foreseen			
Spain	LILW-surf	El Cabril	35,000[4]	1992-2013
Sweden	LILW-surf LILW-deep LILW-surf LILW-surf LILW-surf LILW-surf	SFR SFL3-5 OKG Ringhals Forsmark Studsvik	60,000 25,000 9,000 10,000 10,000 1,625	1988-2020 2008- 1990-2010 1993-2010 1988-2010 1988-2010
United Kingdom	LLW LLW ILW/LLW	Drigg Dounreay to be selected	1,400,000 30,000 400,000	until ~2050 until ~2010 until ~2060

1 Austria, Denmark, Greece, Ireland, Luxembourg and Portugal have no current plans for disposal facilities.

2 Volume of waste intended for disposal.

3 Includes volume available for HLW and spent fuel.

4 As delivered by the producers, equivalent to some 100.000 m^3 actually disposed, including the concrete container.

TABLE M: LIST OF NUCLEAR INSTALLATIONS IN VARIOUS STAGES OF DECOMMISSIONING

AUSTRIA

NAME	TYPE	Oper. Period	STAGE	COMMENTS
No decommissioning activities in Austria				

BELGIUM

NAME	TYPE	Oper. Period	STAGE	COMMENTS
BR3 MOL	PWR	1962-87	-3	Small reactor plant
Belgoprocess Dessel	-	1965-80	-3	Reprocessing plant

DENMARK

NAME	TYPE	Oper. Period	STAGE	COMMENTS
DR-2	DR	1959-1975	2	Building re-used
Hot cells		1964-1990	2	Building re-used

FINLAND

NAME	TYPE	Oper. Period	STAGE	COMMENTS
No decommissioning activities in Finland				

FRANCE

NAME	TYPE	Oper. Period	STAGE	COMMENTS
G1 MARCOULE	GCR	1956-68	2	Small power reactor
G2 MARCOULE	GCR	1959-80	2	Small power reactor
G3 MARCOULE	GCR	1960-84	2	Small power reactor
CHINON-A1	GCR	1963-73	1,a	Small power reactor

CHINON-A2	GCR	1965-85	2	Large power reactor
CHINON-A3	GCR	1966-90	-2	Large power reactor
CHOOZ A	PWR	1967-91	1	Large power reactor
St LAURENT A1	GCR	1969-90	-2	Large power reactor
St LAURENT A2	GCR	1971-92	-2	Large power reactor
EL 4 Monts d'Arrée	HWR	1967-85	-2	Small power reactor
EL 2 SACLAY	HWR	1952-65	2	Research reactor
EL 3 SACLAY	HWR	1957-79	2	Research reactor
PEGASE Cadarache	PWR	1963-74	2,b	Research reactor
RAPSODIE Cadarache	FBR	1967-83	-2	Research reactor
TRITON Fontenay	PR	1959-82	3	Research reactor
MELUSINE Grenoble	PR	1958-88	2	Research reactor
MINERVE Fontenay	LW-PR	1954-76	3*	Research reactor
ZOE Fontenay	HW	1948-75	2,a	Research reactor
NEREIDE Fontenay	LW-PR	1959-82	3	Research reactor
PEGGY Cadarache	GCR	1961-75	3	Research reactor
CESAR Cadarache	-	1964-74	2	Critical Assembly
MARIUS Cadarache	-	1960-83	2	Critical Assembly
ELAN II B La Hague	-	1970-73	-3,c	Source fabrication plant
ELAN II A Saclay	-	1968-70	3	Pilot plant for Elan II B
AT 1 La Hague	-	1969-79	-3,c	Fuel reprocessing plant
PIVER Marcoule	-	1966-80	3,c	Waste vitrification plant
ATTILA	-	1968-75	3	Dry processing pilot cell
RM 2	-	1964-85	2	Radiometallurgy lab,13 cells
BUILDING 19 Fontenay	-	1957-84	3,c*	Plutonium metallurgy
BUGEY 1	GCR	1972-94	-2	Large Power Reactor

GERMANY

NAME	TYPE	Oper. Period	STAGE	COMMENTS
HDR Grosswelzheim	BWR	1969-71	-3	Large power reactor
KKN Niederaichbach	HWR	1973-74	-3	Large power reactor
KRB A Gundremmingen	BWR	1966-77	-3	Large power reactor
KWL Lingen	BWR	1968-77	1	Large power reactor
MZFR Karlsruhe	HWR	1966-84	-3	Large power reactor
VAK Kahl	BWR	1961-85	-3	Large power reactor
AVR Jülich	HTR	1967-88	-1	Large power reactor
THTR 300 Hamm-Uentrop	HTR	1985-88	-1	Large power reactor
KKR Rheinsberg	PWR	1966-90	-3	Large power reactor
KGR 1 Greifswald	PWR	1973-90	-3	Large power reactor
KGR 2 Greifswald	PWR	1974-90	-3	Large power reactor
KGR 3 Greifswald	PWR	1977-90	-3	Large power reactor
KGR 4 Greifswald	PWR	1979-90	-3	Large power reactor
KGR 5 Greifswald	PWR	1989-90	-3	Large power reactor
KNK-II Karslruhe	FBR	1978-90	-2	Large power reactor
KWW Wurgassen	PWR	1972-94	0	Large power reactor
Otto-Hahn ship reactor	PWR	1968-79	3	Small reactor plant
FR-2 Karlsruhe	HWR	1962-81	2	Small reactor plant
FRJ-1 Merlin Jülich	PR	1962-85	-2	Small reactor plant
RFR Rossendorf	PR	1957-90	-3	Small reactor plant
FRN TRIGA III Neuherberg	TRIGA	1972-82	2	Small reactor plant
FRF-2 Frankfurt	TRIGA	1977-83	2	Small reactor plant
FRG-2 Geesthacht	PR	1963-95	-3	Small reactor plant

Nukem Hanau	-	1960-88	-3	Fuel fabrication plant
WAK Karlsruhe	-	1971-90	-3	Reprocessing plant
HOBEG Hanau	-	1962-88	-3	Fuel fabrication plant
Siemens Brennelementwerk Hanau	-	1968-95	0	Uranium/MOX fuel fabrication plant

GREECE

NAME	TYPE	Oper. Period	STAGE	COMMENTS
No decommissioning activities in Greece				

IRELAND

NAME	TYPE	Oper. Period	STAGE	COMMENTS
No decommissioning activities in Ireland				

ITALY

NAME	TYPE	Oper. Period	STAGE	COMMENTS
GARIGLIANO	BWR	1964-78	-1	Large power reactor
LATINA	GCR	1963-86	-1	Large power reactor
CAORSO	BWR	1978-86	-1	Large power reactor
TRINO	PWR	1964-87	-1	Large power reactor
AVOGADRO Compes	PR	1959-71	2,b	Small reactor plant
ISPRA-1	HWR	1958-74	2	Small reactor plant
Galileo Galilei,Cisam,Pisa	PR	1963-80	2	Small reactor plant
ESSOR Ispra	HWR	1967-83	2	Small reactor plant

LUXEMBOURG

NAME	TYPE	Oper. Period	STAGE	COMMENTS
No decommissioning activities in Luxembourg				

NETHERLANDS

NAME	TYPE	Oper. Period	STAGE	COMMENTS
DODEWAARD	BWR	1968-1997	0	Small power reactor

PORTUGAL

NAME	TYPE	Oper. Period	STAGE	COMMENTS
No decommissioning activities in Portugal				

SPAIN

NAME	TYPE	Oper. Period	STAGE	COMMENTS
VANDELLOS 1	GCR	1972-89	-2	Large power reactor
JEN-1 Madrid	PR	1958-84	1	Small reactor plant
ARB1	Arg	-	-1	Small reactor plant
ARGOS	Arg	-	1	Small reactor plant
CORAL	FBR	-	1	Small reactor plant

SWEDEN

NAME	TYPE	Oper. Period	STAGE	COMMENTS
AGESTA	PHWR	1964-74	1	Small power reactor
R1 Stockholm	GR	1954-70	3	Zero power research reactor
KRITZ Studsvik	PWR	1959-75	3	Zero power research reactor
Alpha-lab Studsvik	Laboratory	1960-75	3	Other installations

UNITED KINGDOM

NAME	TYPE	Oper. Period	STAGE	COMMENTS
DFR Dounreay	FBR	1963-77	-1	Large power reactor
PFR Dounreay	FBR	1975-94	-1	Large power reactor
WAGR Windscale	AGR	1962-81	-3	Large power reactor
SGHWR Winfrith	HWR	1968-90	-1	Large power reactor
BERKELEY 1	GCR	1961-89	-1	Large power reactor
BERKELEY 2	GCR	1961-88	-1	Large power reactor
HUNTERSTON A1	GCR	1964-90	-1	Large power reactor
HUNTERSTON A2	GCR	1964-89	-1	Large power reactor

TRAWSFYNYDD 1	GCR	1965-93	-1	Large power reactor
TRAWSFYNYDD 2	GCR	1965-93	-1	Large power reactor
WINDSCALE Pile 1	GR	1950-57	d,e	Small reactor plant
WINDSCALE Pile 2	GR	1951-58	e	Small reactor plant
Merlin Aldermaston	PR	1959-62	1	Small reactor plant
BEPO Harwell	GR	1948-68	1	Small reactor plant
DMTR Dounreay	HWR	1958-69	1	Small reactor plant
DRAGON Winfrith	HTR	1965-76	1	Small reactor plant
ZEBRA	?	1967-82	2	Small reactor plant
DIDO Harwell	HWR	1956-90	-1	Small reactor plant
PLUTO Harwell	HWR	1956-90	-1	Small reactor plant
GLEEP	GR	1947-90	2	Small reactor plant
NESTOR	Arg	1961-95	1	Small reactor plant
B212 Caesium plant (S)	-	1956-58	-3	Other installation
B206 Solvent recovery (S)	-	1952-63	-3	Other installation
B29 Fuel storage (S)	-	1952-64	-1	Other installation
B205 Fuel reprocessing (S)	-	1957-68	-3	Other installation
B204 Fuel reprocessing (S)	-	1952-73	-3	Other installation
B207 Uranium purification, (S)	-	1952-73	-3	Other installation
Co-precipitation plant (S)	-	1969-76	?	Other installation
Uranium enrichment plant(C)	-	1953-82	-3	Other installation
B100-103 U recovery (S)	-	1952-85	3,f	Other installation
B209 Pu finishing plant (S)	-	1953-86	-3	Other installation
B203 Pu recovery plant (S)	-	1956-86	-3	Other installation
B30 fuel storage pond (S)	-	1960-86	-2	Other installation
B277 fast reactor fuel prod(S)	-	1970-88	-3	Other installation
B205 Pu corridors (S)	-	1964-88	-3	Other installation

Description of terms:

REACTOR TYPES	GCR	Gas-cooled reactor
	HWR	Heavy Water moderated reactor
	PWR	Pressurised water reactor
	PR	Pool type reactor
	FBR	Fast-breeder reactor
	BWR	Boiling water reactor
	HTR	High temperature reactor
	Arg	Argonaut type reactor
	AGR	Advance gas-cooled reactor
	GR	Air-cooled graphite reactor
	PHWR	Pressurised Heavy Water Reactor

DECOMMISSIONING STAGE	0	Decommissioning announced
	1	Decommissioned to stage 1
	2	Decommissioned to stage 2
	3	Decommissioned to stage 3
	3*	Decommissioned to stage 3 with exception of civil engineering
	-x	Decommissioning in progress to stage x

Complementary information	a	partly converted into a museum
	b	converted into a spent fuel facility
	c	equipment dismantled: building to be re-used for...
	d	contains damaged fuel elements
	e	chimney being partially dismantled
	f	used as radioactive waste store
	S	Sellafield (UK)
	C	Capenhurst (UK)

9. UNITS

Bq	Becquerel, activity in disintegrations per second
Bq/g or Bq/kg	activity per unit mass
ECU	european currency unit
GBq	GigaBecquerel
GWe	GigaWatt electrical (unit of electrical power production)
kg/h	kilogram per hour (throughput)
kWh	kiloWatt hour (unit of energy)
m^3	cubic meter
MECU	million ECU
μSv	microSievert (unit of dose)
mSv	milliSievert (unit of dose)
MWe	MegaWatt electrical (unit of electrical power production)
MWh	MegaWatt hour (unit of energy)
tU	tonnes uranium (in the context of this report equivalent to tonnes of heavy metal)

10. ABBREVIATIONS AND ACRONYMS

AEC	Atomic Energy Commission (AEC of Greece in the context of this report)
AGR	advanced gas-cooled reactor
ANDRA	Agence Nationale pour la Gestion des Déchets Radioactifs (French radioactive waste management agency)
ANPA	Agenzia Nazionale Protezione Ambiente
AVR	Arbeitsgemeinschaft Versuchs Reaktor GmbH (German test reactor at Jülich)
BfS	Bundesamt für Strahlenschutz (Germany)
BN	Belgonucléaire (Belgian fuel fabrication company)
BNFL	British Nuclear Fuels Limited (now BNF plc)
BR-3	Belgian reactor 3
BWR	boiling water reactor
CBNM	Centraal Bureau voor Nukleaire Meetingen
CD-ROM	compact disc - read only memory
CEN/SCK	Centre d'Etudes de l'Energie Nucléaire / Studiecentrum voor Kernenergie
CILVA	Centrale Installatie voor Laag Radioaktief Afval
CLAB	Centralt Lager för Använt Kärnbränsle (Swedish interim storage facility for spent fuel)
COGEMA	Compagnie Générale des Matières Nucléaires
COM(year)number	identifies European Commission documents available in all Community languages
COVRA	Centrale Organisatie voor Radioactief Afval
DBE	Deutsche Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe mbH (German radioactive waste management agency)

DPSR	Department of Radiological Protection and Safety (Portugal)
DSIN	Direction de la Sûreté des Installations Nucléaires (France)
EARP	enhanced actinide removal plant
EC	European Community
EdF	Electricité de France
EEC	European Economic Community
EL-4	réacteur à eau lourde (in France)
ENEA	Ente per le Nuove Tecnologie, l'Energia e l'Ambiente
ENEL	Ente Nazionale per l'Energia Elettrica
ENRESA	Empresa Nacional de Residuos Radiactivos SA (Spanish radioactive waste management agency)
ERAM	Endlager für Radioaktive Abfälle Morsleben
EU	European Union
EUR-xxxxx	reference number of reports published in the EUR-series at the Official Publication Office in Luxemburg
EURATOM	European Atomic Energy Community
FBFC	Franco-Belge de Fabrication de Combustibles
FBR	fast-breeder reactor
GCR	gas-cooled reactor
GDR	German Democratic Republic
GGR	gas-cooled graphite-moderated reactor
GNS	Gesellschaft für Nuklear Service
HADES	High Activity Disposal Experimental Site (situated on SCK-CEN site at Mol, Belgium)
HFR	high flux reactor
HLW	high-level waste

HLW/SFuDD	high-level waste or spent fuel destined for direct disposal
HRL	Hard rock Laboratory (Äspö, Sweden)
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
INES	international nuclear event scale
IVO	Imatran Voima Oy (Finnish NPP company)
KRB-A	Kernkraftwerk RWE-Bayernwerk - A (Gundremmingen A, BWR in operation 1966-77)
LILW	low- and intermediate-level waste
LLW	low-level waste
Ltd	limited
LWR	light-water reactor
MLW	medium-level waste
MOX	mixed oxide (fuel)
MTR	materials test reactor
NEA	Nuclear Energy Agency (of OECD)
NIREX	Nuclear Industry Radioactive Waste Executive (radioactive waste management agency of the UK)
NKS	Nordisk Kerne-Sikkerheds-Forskning
NPP	nuclear power plant
NUCLECO	Nucleare Ecologia
OECD	Organisation for Economic Co-operation and Development
OKG	Oskarshamnskraftgrupp AB (Swedish NPP Company)
ONDRAF/NIRAS	Organisme National des Déchets Radioactifs et des Matières Fissiles/Nationale Instelling voor het Beheer van Radioactief Afval en Splijtstoffen

PAAG	Performance Assessment Advisory Group (of NEA)
PAGIS	Performance Assessment for Geological Isolation Systems
PAMELA	Pilotanlage Mol zur Erzeugung Lagerfähiger Abfälle
plc	public limited company (in the UK)
POSIVA	(Finnish radioactive waste management agency)
PWR	pressurised water reactor
R&D	research and development
RADWASS	radioactive waste safety standards
RR	research reactor
RWE	Rheinisch Westfälische Elektrizitätswerke (German electricity producer)
RWMC	Radioactive Waste Management Committee
SEC(year)number	European Commission working document
SEDE	Site Evaluation and Design of Experiments for Radioactive Waste Disposal (NEA expert group)
SFL	Slutförvar för Långlivat Radioaktivt Avfall
SFR	Slutförvar för Drifavfall
SFuDD	spent fuel destined for direct disposal
SFuR	spent fuel destined for reprocessing
SKB	Svensk Kärnbränslehantering AB (Sweden)
SKI	Statens Kärnkraftinspektion (Swedish nuclear safety authority)
SNR-300	Schneller Natriumgekühlter Reaktor (German fast breeder reactor with 300 MWe capacity)
SSI	Statens Strålskyddsinstitut
STUK	Säteilyturvakeskus (Finnish radiation and nuclear safety authority)

TECDOC	technical document (issued by the IAEA)
TEN	The European Nucworker
THTR	Thorium Hochtemperatur-Reaktor (at Hamm-Uentrop in Germany)
TSO	Technical Support Organisation
TVO	Teollisuuden Voima Oy (Finnish NPP company)
UKAEA	United Kingdom Atomic Energy Authority
URF	underground research facility
VVER-nnnn	(Russian designed pressurised water reactor)
WAGR	Windscale advanced gas-cooled reactor
WAK	Wiederaufarbeitungsanlage Karlsruhe
ZAB	Zwischenlager für abgebrannte Brennstäbe
ZLN	Zentrallager Nord