INTERNATIONAL NUCLEAR SOCIETIES COUNCIL (INSC)

CURRENT ISSUES IN NUCLEAR ENERGY

RADIOACTIVE WASTE

August 2002

Published by the American Nuclear Society, Inc.
555 North Kensington Avenue
La Grange Park, Illinois 60526 USA

MEMBERS OF THE INTERNATIONAL NUCLEAR SOCIETIES COUNCIL

American Nuclear Society (ANS)
Asociación Argentina de Tecnologia Nuclear (AATN)
Associação Brasileira de Energia Nuclear (ABEN)
Atomic Energy Society of Japan (AESJ)
Australian Nuclear Association (ANA)
Canadian Nuclear Society (CNS)
Egyptian Society of Nuclear Science and Applications (ESNSA)
European Nuclear Society (ENS)
Austrian Nuclear Society
Belarus Nuclear Society
Belgian Nuclear Society
British Nuclear Energy Society
Bulgarian Nuclear Society
Croatian Nuclear Society
Czech Nuclear Society
Danish Nuclear Society
Finnish Nuclear Society
French Nuclear Energy Society
German Nuclear Society
Hungarian Nuclear Society
The Institution of Nuclear Engineers
Israel Nuclear Society
Italian Nuclear Association
Lithuanian Nuclear Energy Association
Netherlands Nuclear Society
Nuclear Society of Russia
Nuclear Society of Slovenia
Polish Nuclear Society
Romanian Nuclear Energy Association
Slovak Nuclear Society
Spanish Nuclear Society
Swedish Nuclear Society
Swiss Nuclear Society
Ukrainian Nuclear Society
Yugoslav Nuclear Society
Indian Nuclear Society (INS)
Israel Nuclear Society (INS)
Korean Nuclear Society (KNS)
Latin American Section (LAS)
Nuclear Energy Society Taipei, China (NEST)
Pakistan Nuclear Society
Sociedad Nuclear Mexicana (SNM)

MEMBERS OF THE TASK FORCE

Chairman

John Mathieson, European Nuclear Society
E-mail: john.mathieson@nirex.co.uk

Members
Clarence J. Hardy, Australian Nuclear Association, Australia
E-mail: cjhardy@ozemail.com.au

Alvaro Rodriguez Beceiro, European Nuclear Society
E-mail: arob@enresa.es

Dr. Osamu Tochiyama, Atomic Energy Society of Japan
E-mail: osamu.tochiyama@qse.tohoku.ac.jp

Der-Yu Hsia, Nuclear Energy Society of Taiwan
E-mail: hsia@iner.aee.gov.tw

Mr. Jose-Luis Delgado, Mexican Nuclear Society
E-mail: jldelgado@cnsns.gob.mx

CONTENTS

FOREWORD

The purpose of this document is to provide top-level information on the subject of radioactive waste management disposal among the member societies of the International Nuclear Societies Council (INSC). The aim here is to provide an overview on the subject from an international perspective and to provide access to Internet resources on the subject, including access to the relevant radwaste management organization in the country concerned.

We wish to acknowledge that much of the material in this document has been provided by the national radwaste management organizations of many countries. Where appropriate, we have provided links to their particular Websites, where updated information is available.

Chang Kun Lee
Chairman, International Nuclear Societies Council

1. WHAT IS RADIOACTIVE WASTE MANAGEMENT?

1. WHAT IS RADIOACTIVE WASTE MANAGEMENT?

In introducing the subject of radioactive waste (radwaste) we must first agree on what is meant by the word *waste*. The organization that has considered this point in greatest detail is the International Atomic Energy Agency (IAEA), (see www.iaea.org). For the purposes of this document, we have adopted their definition of radioactive waste[1]:

> Any material that contains or is contaminated by radionuclides at concentrations or radioactivity levels greater than the exempted quantities established by the competent authorities and for which no use is foreseen.

It is recognized that different countries may have different interpretations; however, the important part of the definition is “for which no use is foreseen.” For some types of waste this is self-evident (see Fig. 1 and Sec. 2). However, some countries, such as the United Kingdom, Japan, and France, for example, would regard spent fuel as a resource, as it is recycled, whereas Finland, the United States, Sweden, and others would regard it as a waste. The interpretation, therefore, can depend as much on national policy as well as any scientific or technical description.

Fig. 1. Example of radioactive waste.

We must also be clear what we mean by *disposal*. Again, we adopt the IAEA definition:

> The emplacement of waste in an approved, specified facility …without the intention of retrieval….

But again the reality of the definition depends as much on government policy and public perception. In this case it is the role of retrievability in the disposal concept. Some countries require retrievability to be an option postdisposal. For example, even if spent fuel were regarded as a waste in this generation, future ones may regard it as a resource.

Moreover, there is often the public perception that disposal is too final — raising the question, What if something goes wrong and we need to get it back? Radioactive waste management is, therefore, about addressing both technical and sociopolitical aspects.

The purpose of this publication is to look at radioactive waste management from an international perspective, to provide access to Internet resources relating to the disposal of solid radioactive waste, and to consider how different countries are applying top-level principles of radwaste management.

We concentrate here on the disposal of solid radioactive waste, but many of the same principles apply to discharges of liquid and gaseous radioactive effluents as well. We also realize that discharges from repositories may take place over many thousands and tens of thousands of years. Radioactivity does not implicitly recognize national boundaries, nor on the time scales we are talking about for geologic repositories, do national borders themselves remain constant. It is, therefore, important that common principles be applied around the world. Taking IAEA wording again, the main objective of radwaste management

> … is to deal with radioactive waste in a manner that protects human health and the environment now and in the future without imposing undue burdens on future generations.

But this does not mean to say that radwaste disposal solutions have to be found at any cost. We have a responsibility also to the present generation, which has to pay for disposal to provide an environmental solution that is economical but is consistent with providing adequate safety—an optimized solution. Further, the cost implications should be brought home directly to the people responsible for creating the problem — the “polluter-pays” principle.

Radwaste management and disposal policies must also be consistent with higher-level policies aimed at enhancing the environment—in particular, policies such as sustainable development, often defined as development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs.

Sustainable Development

The concept of sustainable development was first introduced in 1987 in the United Nations report “Our Common Future” (also called The Brundtland Report). This report was prepared by the World Commission on Environment and Development, which was chaired by Gro Harlem Brundtland, then the prime minister of Norway. The commission defined sustainable development as “meeting the needs of the present without compromising the ability of future generations to meet their own needs.” Many scientists believe that we must adopt sustainable practices and policies in order to maintain or better the current state of our planet.

The *International Institute for Sustainable Developmen*t has produced a series of World Wide Web documents that discuss the meaning and basic principles of practice behind sustainable development. These resources are available from *www.iisd.org*.

2. WHERE DOES RADIOACTIVE WASTE COME FROM?

2. WHERE DOES RADIOACTIVE WASTE COME FROM?

2.1 Introduction

A general principle of radwaste management is that waste should not be created unnecessarily and that it should be safely treated and disposed of at an appropriate time and in an appropriate way. In undertaking radioactive waste management, we must also ensure protection of the environment, workers, and members of the public.

Regardless of one's views on nuclear issues, radioactive waste exists and is a consequence of a number of activities:

1. nuclear power plants both during electricity generation and during dismantling (decommissioning) (Fig. 2)
2. nuclear propulsion, e.g., submarines and ice-breakers
3. nuclear weapons manufacture
4. spent nuclear fuel reprocessing at COGEMA's facilities in France and British Nuclear Fuels plc's (BNFL) Sellafield plant in the United Kingdom
5. occurrence of contaminated waste from incidents such as Chernobyl and poor historical practices at nuclear sites
6. the application of radioactivity in medicine and industry
7. the enhancement of naturally occurring radionuclides (NORM) due to human activity, such as drilling muds in the oil industry.

Fig. 2. Decommissioning Vandellós I nuclear power plant in Spain (courtesy of ENRESA).

2.2 Types of Radioactive Waste

Radioactive waste consists of a variety of materials having different physical and chemical properties containing different types of radioactivity (see Fig. 3). There are no international standard definitions of waste, although the IAEA has proposed five categories,[2] and each nation tends to have developed its own classification system. In addition, the European Commission (EC) has proposed a classification system for application in the European Union (EU) (see www.europa.eu.int/comm/energy/nuclear).

The EC notes that the purpose of a classification system is to improve communication and facilitate information management by providing a "good descriptive tool," enabling easier communication with politicians and the public.

The following is a general categorization of waste types:

1. Exempt waste: Radioactive waste that can be safely disposed of with ordinary refuse. Some countries define this as very low level waste (VLLW) and provide separate disposal facilities (e.g., Andra).
2. Transition radioactive waste: A type of radioactive waste (mainly from medical origin) that will decay within the period of temporary storage and may then be suitable for management outside the regulatory control system, subject to compliance with clearance levels.
3. Low-level waste (LLW): Consisting of trash and debris from routine operations and decommissioning. It is primarily low-concentration beta/gamma contamination but may include alpha-contaminated material. It does not usually require special handling unless contaminated with alpha emitters.

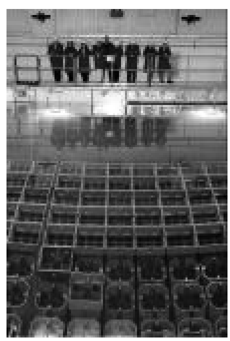
a) Very low-level waste (courtesy of Andra).

b) Typical low-level waste (courtesy of BNFL).

c) Long-lived intermediate-level waste from reprocessing spent Magnox fuel in 500-litre drum (courtesy of BNFL).

d) TRU waste in 55-gallon drums for disposal at the DOE WIPP site (courtesy of DOE).

e) Vitrifed HLW production. The 1.35-m-high canister weighs 490 kg (courtesy of COGEMA).



f) Spent nuclear fuel storage underwater (courtesy of SKB).

Fig. 3. Examples of radioactive wastes.

4. Low- and intermediate-level waste (LILW) (EC): In LILW the concentration of radionuclides is such that generation of thermal power during its disposal is sufficiently low. These acceptable thermal power values are site specific following safety assessments.
5. Intermediate (medium)-level waste (ILW): Wastes containing higher concentrations of beta/gamma contamination and sometimes alpha emitters. There is little heat output from this category of waste, but it usually requires remote handling. Such waste originates from routine power station maintenance operations, e.g., used ion-exchange resins and filter cartridges. Some countries, notably the United States, Canada, and Japan, do not use the ILW classification category; however, some types of LLW, such as "greater than Class C" in the United States, would equate to ILW elsewhere.

   These examples can be further classified as short lived (usually meaning radionuclides with a half-life of less than 30 years) and long lived. Fuel reprocessing wastes, such as the canning materials, also are classed as ILW but contain long-lived species of radionuclides, which require deep disposal.
6. Transuranic waste: Some countries choose to categorize alpha-bearing waste separately. For example, in the United States, transuranic waste (TRU) is defined as

   … waste containing more than 100 nanocuries of alpha-emitting transuranic isotopes, with half lives greater than twenty years, per gram of waste … .
7. High-level waste (HLW): This is waste with such a concentration of radionuclides that generation of thermal power has to be considered during its storage and disposal (the

heat generation level is site specific and arises mainly from treatment/conditioning of spent nuclear fuel).

Depending on the national strategy adopted for the back end of the fuel cycle, HLW may comprise either spent fuel or the highly active raffinate resulting from the first stage of fuel reprocessing. This raffinate is often immobilized in a suitable matrix for eventual disposal—glass and synroc are two examples of such a matrix. It contains high concentrations of beta/gamma-emitting fission products and alpha-emitting actinides. HLW is de facto a long-lived waste type and requires remote handling due to the radiation levels. In some countries, the definition of HLW encompasses spent fuel.

Comment

Recognizing that the classification of waste is not intended to prescribe disposal routes, its misuse can create difficulties in optimizing the disposal of wastes that lie close to the category boundaries. For example, some kinds of spent fuel, such as fuel fragments or low-irradiation fuel, could be disposed of alongside ILW, without imposing significant additional risk.

Accordingly, safety assessments determine the acceptability of disposal by any particular route. It is important, therefore, to recognize that while classifications are a useful shorthand, they will not in themselves constrain the choice of disposal routes.

2.3 How Much Is There?

In the Organization for Economic Cooperation and Development (OECD) countries, approximately 300 million tonnes of toxic waste is produced each year. By way of comparison, a 1000-MWe coal plant produces approximately 300 000 tonnes of ash alone per year, containing among other things radioactive material and heavy metals that end up in landfill sites and in the atmosphere.

The generation of electricity from a typical 1000-MWe nuclear power station, which would supply the needs of a city the size of Amsterdam, produces approximately 300 m^3 of LILW per year and some 30 tonnes of HLW. In total, each year, nuclear power generation facilities world-wide produce about 200 000 m^3 of LILW and 10 000 m^3 of HLW (including spent fuel designated as waste).

The IAEA compiles figures from around the world every few years and produces reports that are available through their Website. The IAEA admits that to produce global figures for waste amounts is very difficult—not because it is unrecorded but because different countries have different classification schemes. The IAEA's Waste Management Database contains information on national radioactive waste inventories and is available on-line, following registration, at http://www-newmdb.iaea.org/.

2.4 How Is It Transported?

Transport of radioactive waste is necessary when the waste is produced at a site other than the one where it is conditioned, stored, or disposed of. Radioactive materials are routinely and safely transported in many countries by road, rail, sea (Fig. 4), and air.

The transport regulations in most countries are consistent with the IAEA Regulations on the Safe Transport of Radioactive Materials. These regulations stipulate the type of packaging that must be used, its labeling, and permitted modes of transport. Before being accepted, transport packages are type tested and must be able to withstand drop tests from various heights (Fig. 5), fire tests, leak tests, immersion tests, etc., without releasing their radioactive contents. These requirements must prevent, even in case of a severe accident, the release of radioactive material that would give rise to unacceptable doses to individuals.

Fig. 4. The MS Sigyn carries radwaste between Swedish nuclear sites on the Baltic coast (courtesy of SKB).

Fig. 5. Spent-fuel transportation cask undergoes a drop test (courtesy of GNS).

There are a number of international treaties and conventions on transboundary shipments of radioactive waste, and these are referred to later in Sec. 7.

3. PRINCIPLES AND OBJECTIVES OF RADIOACTIVE WASTE MANAGEMENT

3. Principles and Objectives of Radioactive Waste Management

3.1 High-Level Principles

The primary objective of radwaste management is to protect humans and their environment, both now and in the future, from potential hazards arising from such wastes. Safe radwaste management involves the application of technology and resources in a regulated manner so that the public, workers, and the environment are protected in accordance with accepted national and international standards.

Many countries have signed and ratified the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (see www.iaea.org/ns/rasanet/programme/wastesafety/Safety_Conventions).

In summary, this document states that radioactive waste shall be managed in ways that

1. ensure that criticality and removal of residual heat generated during spent-fuel and radioactive waste management are adequately addressed
2. ensure that the generation of radioactive waste is kept to the minimum practicable
3. take into account interdependencies among the different steps in radioactive waste management
4. provide for effective protection of individuals, society, and the environment by applying at the national level suitable protective methods as approved by the regulatory body within the framework of its national legislation which has due regard to internationally endorsed criteria and standards
5. take into account the biological, chemical, and other hazards that may be associated with radioactive waste management
6. strive to avoid actions that impose reasonably predictable impacts on future generations greater than those permitted for the current generation
7. seek to avoid imposing undue burdens on future generations.

3.2 Institutional Frameworks

The IAEA provides guidance[3] relating to the establishment of appropriate radioactive waste management structures within a country, highlighting the importance of having well-defined responsibilities. In particular, attention is paid to the relationships between

1. the state, responsible for policy
2. the regulator, responsible for regulation and licensing
3. waste production by industry and the like
4. waste disposal by a separate waste management organization.

Around the world, many examples exist of these arrangements. However, precise arrangements differ in detail in that there are examples where the waste producers undertake some aspects of disposal. For example, BNFL and United Kingdom Atomic Energy Authority (UKAEA) (UK waste producers) have responsibility to dispose of LLW at Drigg and Dounreay, respectively. In Finland, the operators of the two nuclear power station sites manage LLW and short-lived ILW disposal facilities. Differences are also apparent, particularly with respect to responsibilities for treatment and conditioning, transport, and storage.

It should be emphasized that precise arrangements never stray far from the IAEA principles; however, they do differ in their detail to reflect national differences in economic, social, political, legal, institutional, and geographic structures.

Table 1 provides the names of the radioactive waste management organizations and links to their Websites and those of associated organizations.

Table 1.
Radioactive Waste Management Organizations in Some Countries

Country	Agency	Useful Websites
Australia	Department of Education, Science, and Training (DEST)	http://www.dest.gov.au/radwaste/

Table 1. (cont'd.)
Radioactive Waste Management Organizations in Some Countries

Country	Agency	Useful Websites
Belgium	ONDRAF/NIRAS	www.nirond.be http://hades.sckcen.be
Canada	None as yet, but law passed in 2001 enables one to be created	www.aecl.ca www.nrcan.gc.ca http://www.opg.com/ops/N_waste_man.asp
Czech Republic	RAWRA	www.surao.ca/english/index-en.html
Germany	BfS (subcontracted to DBE)	www.bfs.de www.dbe.de
Finland	Posiva Oy	www.posiva.fi www.tvo.fi www.fortum.com www.stuk.fi
France	ANDRA	www.andra.fr www.cogema.fr www.cea.fr
Korea	None as yet	www.kaeri.re.kr
Hungary	PURAM	www.rhk.hu
Italy	ENEA undertakes some functions	http://www.casaccia.enea.it/taskforce/
Netherlands	COVRA	http://www.vrom.nl.international/ http://www.nrg-nl.com/
Japan	NUMO	www.numo.org.jp www.jnfl.co.jp www.miti.go.jp
Russia	RADON MINATOM	www.radon.ru www.minatom.ru
Slovenia	Agency RAO	www.sigov.si/arao/aarao.html
Spain	ENRESA	www.enresa.es
Sweden	SKB	www.skb.se
Switzerland	NAGRA	www.nagra.ch
Taiwan	Fuel cycle and materials administration (FCMA) is the regulator, and there are plans for establishing a waste management organization	www.fcma.aec.gov.tw www.taipower.co.tw

Table 1. (cont'd.)
Radioactive Waste Management Organizations in Some Countries

Country	Agency	Useful Websites
United Kingdom	UK Nirex Ltd	www.nirex.co.uk www.bnfl.co.uk www.ukaea.org
United States	U.S. Department of Energy—Office of Civilan Radioactive Waste Management for civilian HLW DOE Environmental Management for TRU State compacts for LLW	www.rw.doe.gov www.em.doe.gov/dnfsbrpt/ www.wipp.carlsbad.nm.us/ www.envirocareutah.com/ www.ymp.gov/

3.3 Financing Schemes

The polluter-pays principle is intended to ensure that (any) waste producer makes proper provision for dealing safely with its waste and that costs are passed on to those who benefit from its production. Generic solutions for financing radioactive waste disposal address the issues of who pays and how they should pay. In brief, the options are

1. waste producers, directly through a tariff mechanism to the waste disposal organization
2. electricity producers, through payments into a fund from levies on electricity generation and then to the waste disposal organization
3. government or third parties through subsidies to the waste disposal organization.

In addition, there is a general international consensus that all liabilities (decommissioning and waste disposal) should be identified, reported, and reviewed periodically and that there should be mechanisms to ensure that funds are available to meet these liabilities when they arise.

The fundamental features of radioactive waste management are extremely challenging from an economic perspective. Radwaste management is not a conventional industry, where demand and supply can be easily matched; there are confounding factors such as the long time scales involved. Radwaste management and, in particular, the design, construction, and operation of an underground repository are lengthy processes, typically continuing many tens of years after waste has actually been generated.

The long time scales associated with the design, construction, and operation of a radwaste repository are particularly problematic in the context of changes in the state of technological knowledge. Once financial capital has been spent in the pursuit of a particular technical solution, it may be difficult to take advantage of any other options that (for reasons of technological advancement) may present themselves. Capital expended quickly becomes sunk and irretrievable. The financing mechanism, therefore, needs to be robust in the face of irreversibility and technological change.

The principle of polluter pays stipulates that the costs of dealing with waste should, as far as possible, burden those who benefited from its production. In the case of radwaste management, this implies that charges should be levied on those responsible for waste generation (and where applicable, their customers). Waste is typically produced by a number of disparate sources (electricity, fuel cycle, research, etc.), and the funding mechanism needs to take this into account.

In most cases, operation of the financing scheme involves the buildup of a fund to cover future waste management costs; this is no more than a special form of pension scheme. The funds are sometimes segregated and managed separately, either directly by the waste producer, the waste management organization, or the government, or by independent fund managers.

For more discussion on this subject the reader is referred to Ref. 4. The EC has also carried out a comparative study of financing schemes around the world (see http://www.europa.eu.int/comm/energy/nuclear/synopses.htm#18185).

3.4 Deep Geological Disposal

3.4.1 Concept

Deep disposal in stable geological formations is a means of safe containment of long-lived radioactive materials (long-lived ILW, HLW, and spent nuclear fuel) for many thousands of years. Deep disposal ensures that any risk from exposure due to accidental intervention or natural disturbance is reduced to a very low level. The main route by which radionuclides in the waste could return to the biosphere is movement in groundwater that may eventually reach the surface to enter the environment.

Prior to the construction and operation of a repository, all countries would require the proponent, usually the waste management organization, to go through a licensing process with the regulators. This process is aimed inter alia at testing the operational (which may include the transport arrangements) and postclosure safety aspects of the concept to demonstrate that the proposal is based on sound scientific knowledge. Such an exercise is often referred to as performance assessment, and the process may involve several iterations as knowledge about a site increases through more detailed site characterization.

Repository postclosure performance assessments attempt to evaluate the radiological safety of a repository after it has been closed and sealed. Different regulators in different countries have their own requirements, but in essence they all require safety performance to be assessed against levels of radiation dose or risk to individuals in the distant future. For near-surface repositories this may be about 300 years (i.e., ten half-lives of short-lived waste) or 10 000 years or longer for long-lived wastes.

All repository concepts are based on the understanding that some radioactivity will be released from the facility at some time in the future and find its way back to human environment (see Fig. 6).

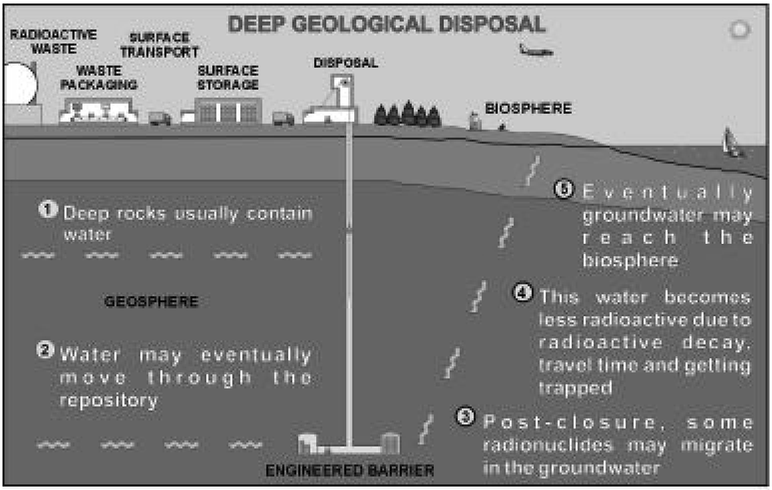


Fig. 6. Deep geological disposal concept.

The role of a radioactive waste management organization is to ensure that these very long time scales are considered when radioactive waste is conditioned and packaged before being put into interim storage or sent for final disposal. This time-scale issue has particular resonance in relation to

1. the longevity of the engineered (manufactured) barriers that are intended to keep the radionuclides within the confines of a repository—mostly steel and cement for an ILW repository, or copper and clay for a spent-fuel repository

2. the rate of migration of radionuclides through the rocks surrounding a repository (primarily through transport in groundwater, see Fig. 6)
3. the way that one assesses safety for human generations living in the distant future.

A useful and frequently employed tool for addressing the first two of these questions is the use of analog data. In the case of the engineered barriers, evidence can be obtained from so-called anthropogenic analogs: studies of the survival, over thousands of years, of objects made by humans from metal or concrete and the environmental conditions that allow this survival. For the second question, that of migration of radionuclides through the surrounding rocks, natural analogs may be useful. (See Sec. 3.4.4.)

The third issue, the way that, one judges safety for generations living in the distant future, is usually addressed by examining outcomes for a range of possible climate states. Uncertainties, with respect to human habits for instance, may be addressed by making assumptions that err on the side of safety, that the exposed population only eats produce from contaminated soil, for example. Work by the IAEA and guidance from the International Commission on Radiological Protection (ICRP) has done much to build an international consensus in this area.

Mathematical models are utilized to calculate the resultant risk of death or radiation dose that may arise from

1. the groundwater pathway, in which water will slowly move through the repository and may carry away dissolved radionuclides
2. the gas pathway, in which there could be the release of gases that find their way back to the biosphere
3. the human intrusion pathway, in which some future geologic worker may drill into a repository or the groundwater plume and become exposed.

A typical output of a mathematical model is shown in Fig. 7. Note that the peak risk (of death) or dose can be very many years into the future for a deep repository.

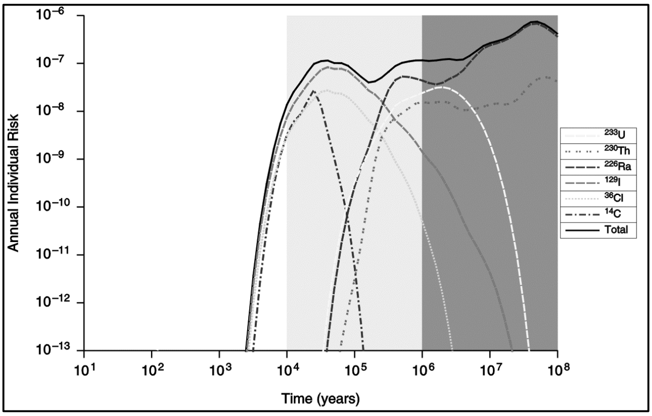


Fig. 7. Typical output for a risk assessment for a deep repository (note log scale) (courtesy of Nirex).

3.4.2 The Question of Time Scales

The very long half-lives of some of the radionuclides present in radioactive waste ensure that some of the waste will remain potentially hazardous, certainly for thousands, and possibly for millions, of years. There is nothing so very unusual about this. After all, conventionally toxic materials, such as heavy metals, will remain toxic forever—in effect, they have infinite half-lives. Even so, the question of how waste can be managed over thousands of years raises difficult issues. This is primarily because such time scales are well beyond individual human, or even cultural, experience.

A few scientific disciplines, such as geology, archaeology, evolutionary biology and cosmology, successfully consider and deal with very long time scales. So, in geologic terms, *recent* equates to the past 10 000 years, a period in which no major global changes in climate or fauna have occurred. It is primarily from geology that possible long-term precedents appear.

3.4.3 Time Frames in Perspective

Typically, performance assessments address time scales of up to a million years. It is recognized, of course, that as the time frame extends, the calculational uncertainty increases. To express this in a more structured way, calculations may be presented in a series of time frames. These show how different emphases can be placed on different measures of performance in different time frames. In particular, in the more distant time frames, it is appropriate to place increasing reliance on measures that involve comparisons with naturally occurring radioactivity. Table 2 shows time frames that are considered in some performance assessment work; the relevant radionuclides are shown in column 4.

Table 2.
Time Frames in Performance Assessment

Time Frame	**Looking Back**	**Looking Forward**	**Radionuclides (half-life)**
0 to 100 years	A few generations of a family	Institutional control of a repository is envisaged for most of this period; greenhouse-gas effect may affect the climate	^{3}H (12 years) ^{90}Sr (29 years) ^{137}Cs (30 years)
100 to 10 000 years	Upper time limit is comparable to the period since the Middle Stone Age, marking the start of organized society represented by the New Stone Age	Institutional controls assumed to have lapsed during this period The current temperate interglacial conditions expected to persist for most of this time frame	^{14}C (5700 years)

Table 2. (cont'd.)
Time Frames in Performance Assessment

Time Frame	Looking Back	Looking Forward	Radionuclides (half-life)
10 000 to one million years	Duration comparable to the period from the appearance of early humans to the emergence of Homo Sapiens	Glacial/interglacial cycling expected. The sea level would fall by up to 140 m during glacial periods, and glacial or periglacial conditions would occur in Britain for much of the time Major tectonic changes not expected	^{239}Pu (24 000 years) ^{99}Tc (200 000 years) ^{36}Cl (300 000 years)
Beyond one million years	First isolated appearances of early humans in Europe	Major tectonic changes could occur	^{129}I (16 million years) ^{238}U (4500 million years)

3.4.4 Natural and Archaeological Analog Projects

Repository concepts rely on a combination of natural and engineered barriers to provide the required level of long-term safety. Natural analogs[5] are occurrences of high concentrations of natural radioactivity or geological environments similar to those expected in repositories and can make an important input into understanding of repository performance. In this context, both natural and archaeological (manufactured) analogs are used to study the long-term performance of natural and engineered systems, respectively.

For example, the Maqarin site in Jordan contains hyperalkaline material waste—typical of the situation expected in a deep repository; a project there started in 1990 and now involves NAGRA (Switzerland), Ontario Hydro (Canada), Nirex (United Kingdom), SKB (Sweden), and the UK Environment Agency. El Berrocal, a uranium mine in Spain, was studied as a natural analog of uranium migration processes in fractured crystalline rock; a CEC/ENRESA/Nirex cofunded project ran from 1991 to 1995. The Alligator Rivers natural analog project was an investigation of uranium deposits in the Northern Territory of Australia, located primarily at the Koongarra deposit; conditions there make ideal for radionuclide migration studies.

Archaeological analog studies are designed to study the many materials used in radioactive waste management, including metals, cement, bitumen, glass, and clay. Examples are as follows:

1. Copper: A bronze (96% copper) cannon from the warship *Kronan*, which sank in the Baltic in 1676, was found in the clay sediments of the sea bottom. The corrosion over the 300-year period was only about 50 μm. The environmental conditions were similar to those expected in the Swedish KBS3 disposal concept, which envisages the encapsulation of spent fuel in a 0.1-m-thick copper canister surrounded by bentonite clay.

2. Iron: Many iron artifacts do not survive long-term burial in soil. However, a huge intact hoard of Roman iron nails found in Scotland had some of the nails in remarkably good state of preservation. ENRESA is using chemical analysis techniques to study the corrosion of such artifacts.

3. Cements: The Romans used cement in structures such as harbors, thermal baths (see Fig. 8), and the dome of the Pantheon in Rome. Studies on ancient cements, concretes, and mortars have found that their alkaline components are stable over a long time, implying that chemical containment of radionuclides in a repository would also be long-lived.

Fig. 8. Typical lime mortar and stone construction from the Roman Fort and Bath House at Glannoventa (Ravenglass, Cumbria, United Kingdom) (courtesy of Nirex).

4. Bitumen: The earliest recorded use of bitumen goes back more than 5000 years and has been used as a waterproof mortar for stabilizing natural and artificial riverbank walls. The good preservation of ancient inscriptions and ornamentation on bitumen attests to its stability on a millennial time scale.

5. Glass is a naturally occurring material. A well-known example is volcanic obsidian, used as early as the Neolithic period as an alternative to flint. Obsidian is common in the 50- to 55-million-year-old tertiary volcanic rocks of western Scotland. The existence of these and similar rocks suggests that natural glasses can resist devitrification for millions of years.

6. Clay: Some disposal concepts have plastic clay surrounding the waste containers, e.g., bentonite clay or mudrock. Perhaps the best known natural analog for clay forming a barrier to migration of radionuclides is at Cigar Lake in

the Canadian Shield, where a high-grade uranium ore body formed some 1300 million years ago. This ore body is surrounded by a clay-rich envelope 10 to 50 m thick that has helped to keep the ore body intact over much of this time (see Fig. 9).

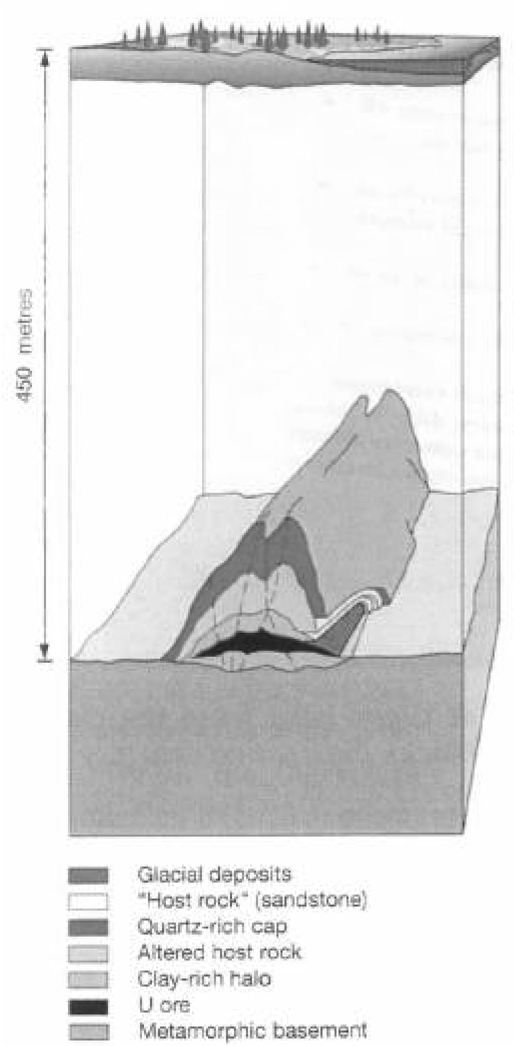


Fig. 9. Cigar Lake, Saskatchewan, Canada.

3.4.5 The Survival of Repository Markers

Work in the United States since the early 1980s has drawn on lessons from the existence of ancient monuments such as Stonehenge and the pyramids of Egypt to design repository warning markers for future generations. For the Yucca Mountain site in Nevada, an array of polished granite monoliths, similar to those at Stonehenge, defining the boundary of the repository has been proposed. In addition, thousands of small warning tablets would be randomly buried throughout a wide area. While some of these materials may be durable, there is a human tendency to reuse metals, and the history of the Avebury stone circle in the United Kingdom, where monoliths were systematically broken to be used in buildings, suggests that there may also be limits to the survivability of stone monoliths.

The U.S. Environmental Protection Agency regulations require that the Waste Isolation Pilot Plant (WIPP) waste disposal site use markers and other passive institutional controls (PICs) to indicate the repository locations. The U.S. Department of Energy (DOE) has identified PICs that are expected to last during the regulatory time frame of 10 000 years. They include

1. a large earthen berm (hill) containing configured objects designed to reflect radar
2. granite monuments, 25 feet high
3. a 40- x 32- x 15-foot-high surface structure engraved with many messages
4. archives: records will be stored, controlled, and maintained at many U.S. locations around the world.

4. WASTE MANAGEMENT STRATEGIES: OPTIONS AND ETHICS

4. WASTE MANAGEMENT STRATEGIES: OPTIONS AND ETHICS

4.1 Introduction

Over the decades since the start of major radwaste research, a variety of disposal and other waste management options have been suggested. This section briefly describes some of the ones that have been proposed.

Interest in the various options focuses on two ethical concerns: intergenerational equity (fairness and equity considerations between generations) and intragenerational equity (fairness and equity considerations within contemporary generations). The Nuclear Energy Agency (NEA) Radioactive Waste Management Committee in 1995 set out in its Opinion on the Environmental and Ethical Basis of Geological Disposal, a set of principles to be used as a guide in making ethical choices about waste management strategy (see www.nea.fr):

1. The liabilities of waste management should be considered when undertaking new projects.
2. Those who generate the wastes should take responsibility and provide the resources for the management of these materials in a way that will not impose undue burdens on future generations.
3. Wastes should be managed in a way that secures an acceptable level of protection for human health and the environment and affords to future generations at least the level of safety that is acceptable today; there seems to be no ethical basis for discounting future health and environmental damage risks.
4. A waste management strategy should not be based on a presumption of a stable societal structure for the indefinite future, nor of technological advance; rather it should aim at bequeathing a passively safe situation that places no reliance on active institutional controls.

The principle of intergenerational equity requires that we show care for future generations by not placing them under any undue burden to care for our waste. In addition, the generation deriving the benefit should pay its costs, and the current generation should not limit the options available to future generations.

4.2 Involving the Public

The public's perception of the future of the nuclear industry is often related to its (negative) perception of radioactive waste management. The level of concern increases when the siting of radioactive waste management facilities is being considered, particularly deep underground repositories. There is often little awareness of the routine technologies applied to most stages of waste management, including disposal.

More and more countries are undertaking the development of disposal facilities (and other large and controversial projects) through a process of formal and informal consultation, communication, and local involvement. These approaches demonstrate increased openness and transparency in decision-making and are often underpinned by legislation (e.g., environmental impact assessment legislation).

There is also a general consensus that the public should be involved principally at the local level in decisions on siting radwaste management facilities. Such involvement may result in the original proposals being modified or even abandoned.

Within the EU there are several directives that require involvement of the public in decisions on radioactive waste management and other nuclear facilities. These are based both on European specific and other international requirements. References to these are given in Sec. 7.

4.3 Spent-Fuel and HLW Management Strategies

Reprocessing refers to the practice of extracting plutonium, uranium, and undesirable fission products and actinides (see Fig. 10). The plutonium is available for reuse as fuel. The uranium may be recycled as fuel or may be used for other applications, but in many cases it is considered to be a waste product because it is depleted in fissionable uranium-235. The fission products and remaining actinides, which constitute only a small fraction of used fuel, are incorporated into a suitable matrix such as glass for eventual disposal.

Although reprocessing changes the characteristics of the waste form, reprocessing used fuel does not alleviate the need for geological disposal.

Decisions on whether to reprocess fuel are determined by the need to balance considerations such as the cost of the different fuel cycle management options, the availability of indigenous fuel resources, the desire of maximizing the energy extracted from uranium resources, the capacity of interim storage for used fuel, and the energy value of recovered uranium and plutonium as feedstock for the manufacture of new fuel. Therefore, the question of whether or not to reprocess used fuel from power reactors is thus not fundamentally a waste management issue.

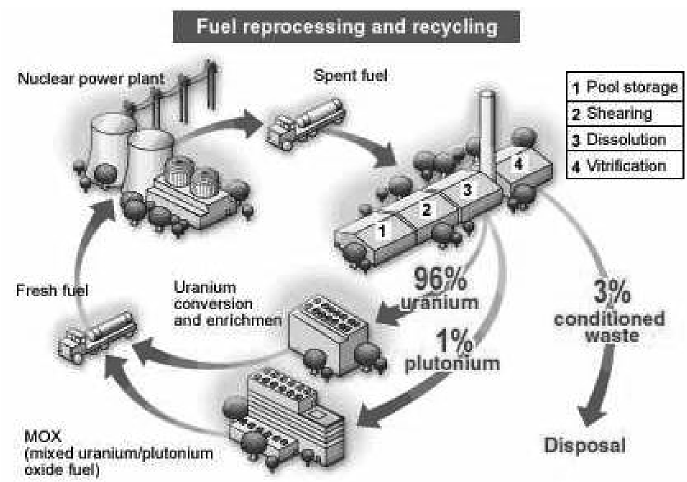


Fig. 10. Spent-fuel reprocessing schematic
(courtesy of COGEMA).

Long-term surface storage, reprocessing, and partitioning and transmutation are potential components in an overall waste management strategy eventually leading to disposal. From this picture, different waste management strategies for spent fuel and HLW can be envisaged, namely,

1. extended or indefinite storage
2. direct disposal (interim storage followed by deep geological disposal with or without waste retrievability)
3. conventional closed cycle (interim storage followed by reprocessing and deep geological disposal with or without waste retrievability); after spent-fuel reprocessing, a geological disposal decision could be deferred leading to the extended or indefinite storage of the resulting high-level liquid wastes or the conditioned vitrified HLWs
4. advanced closed cycle (interim storage followed by reprocessing, partitioning, and transmutation of minor actinides and long-lived fission products, and deep geological disposal with or without waste retrievability). After waste transmutation, a geological disposal decision could be deferred, leading to the extended or indefinite storage of the resulting partitioning and transmutation residues.

4.4 Partitioning and Transmutation

The goal of partitioning and transmutation (P&T) would be to reduce (ideally, to eliminate) the quantity of long-lived radionuclides requiring long-term management by changing (transmuting) long-lived radionuclides into short-lived radionuclides or stable elements. Transmutation is achieved through the use of nuclear reactions, namely, neutron capture leading to fission (for the actinides) or radioactive decay (for fission products). This would be done by bombarding the target radionuclide with neutrons in a nuclear reactor or by a particle accelerator. The target radionuclide would need to have had excluded from it any undesirable nuclides: for example, stable elements that might themselves be transmuted into long-lived radionuclides. This would be achieved by chemical separation, or partitioning, of the target radionuclide prior to irradiation.

The P&T schemes bring together fuel-reprocessing plants, radionuclide separation plants, and various nuclear reactor types to produce nuclear energy while minimizing the creation of long-lived waste. Research would be required to realize these schemes, which suggests that P&T is a technology that will take decades to come to fruition.

Different developments in reprocessing along with advances in reactor design and robotics as well as changes in the regulatory and public environments have recently led to renewed interest in transmutation, particularly in France, Japan, and Russia. However, expert groups of the IAEA and OECD/NEA have emphasized that the current and proposed P&T programs are long-term projects that do not affect the present fuel cycle strategy and that the concept cannot avoid the need for eventual deep geological disposal.

If nuclear fuel is to be reprocessed for recycling and if transmutation of some long-lived radionuclides can be effectively incorporated in the fuel cycle, then P&T may eventually be worthwhile. However, the need for geological disposal would still remain for other long-lived nuclides.

Even if the level of risks posed by geological disposal is considered very low, there is considerable interest in investigating whether a further reduction of the future potential hazard of the waste can be achieved by P&T and at what cost this can be accomplished. Note that the exposure risk in the present or in the near future could appreciably increase due to the complexity of the fuel cycle. The strength of a P&T process would be that it would drastically reduce the hypothetically possible future consequences of unforeseen events. On the other hand, a broad commitment to the development of P&T processes will obscure the fact that the future risks posed by a well-executed deep repository are already deemed to be very small. In addition, the possible deployment of P&T

processes far into the future should not be used as an excuse to postpone development of geological disposal, which will be needed anyway.

There might be potential for widespread use of P&T technology if there is a new upswing in nuclear power development and construction programs in leading industrial countries.

4.5 Long-Term Surface Storage

Long-term surface storage would allow the waste to remain easily monitorable and retrievable, thereby giving future generations greater freedom of choice and giving time for other waste management options to be developed; another advantage is that the technology for waste storage already exists (see Fig. 11). On the other hand, long-term storage implies a commitment to active long-term management and offers little protection against the long-term risks that could arise from loss of social stability and control.

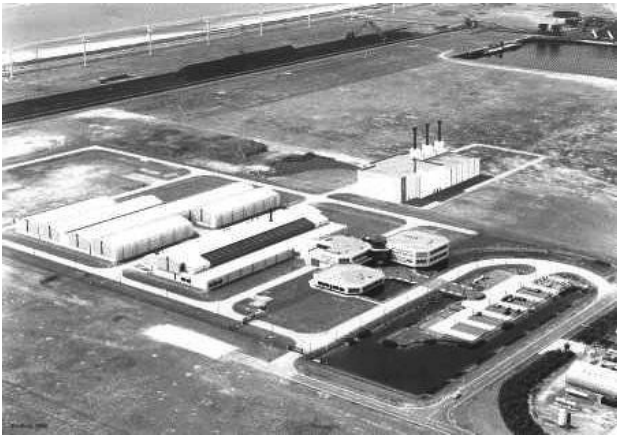


Fig. 11. Surface storage facilities for low-, intermediate- and high-level waste in The Netherlands (courtesy of COVRA).

Therefore, the shortcomings of this option are that

1. storage passes the obligation for continuous supervision and maintenance to future generations
2. storage offers no protection against the long-term risks arising from loss of social stability and control
3. postponing decisions may not end the conflicts relating to the issue but even deepen them in time.

The advantages are that

1. the postponement of disposal gives decades to further develop the final disposal method and to consider any change of plans
2. all in all, further work on preparations for final disposal gives future generations more freedom of choice.

One interpretation of the concept of sustainable development would support the extended storage approach, where one generation would pass on to the next generation a world with equal opportunity. According to this idea of a rolling present, the current generation would have a responsibility to provide to the succeeding generation the skills, resources, and opportunities to deal with any problem the current generation passes on. However, if the present generation delays disposal decisions, awaiting advances in technology, or because storage is cheaper, it should not expect future generations to make a different decision. Such an approach in effect would always pass responsibility for real action to future generations and for this reason could be judged unethical.

4.6 Phased Deep Geological Disposal

A primary motivation for deep geological disposal is based on the principle that the generation that benefited from the activities that produced the radioactive waste should bear the costs of disposal. The safety of a disposal facility should not depend on its long-term maintenance (or even knowledge of its existence) by future generations.

At the same time, there needs to be a degree of flexibility: It would be wrong to take steps that would totally foreclose all other options that future generations might like to take up. A phased approach to deep geological disposal, where the waste remained retrievable over an extended period, might meet this need. Waste retrievability cannot be allowed to lead to a reduction in safety, of course, and the extent to which this might be possible might depend on the chosen geological environment.

Multinational repositories have been suggested as a means of providing a centralized disposal facility for radioactive waste generated in several countries (see Sec. 6.2), with obvious financial and technical advantages.

There is a consensus among experts that sites can be properly identified and characterized, that geological repositories can be designed so that no short-term detriment to populations will result from the waste disposal, and that an acceptable level of safety can be provided for times far into the future. Deep geological repositories exist at the WIPP site (in operation, see Fig. 12) in Carlsbad, New Mexico, in the United States (www.wipp.ws); and Morseleben (now closed) and Konrad (licensed but not operational), in Germany (www.dbe.de); several other sites are under investigation in various countries (see Sec. 5).

Constructing a geological repository ensures that the current generation pays most if not all of the financial and social costs of disposing of nuclear waste generated by the electricity it used. Retrievability of waste allows future generations to decide if there is a better alternative to geological disposal. Monitoring for an extended period allows future generations to confirm that it is operating as expected before fully closing it and facilitates retrieval of waste, if deemed necessary. However, the benefits of postponing the closing and sealing of the repository have to be considered together with the possible risks that such delay may give rise to.

Fig. 12. Deep geological disposal at the WIPP site (courtesy of DOE).

Retrievability is an important ethical consideration because deep geological disposal should not necessarily be considered a totally irreversible process. In this context note that sealing of a site and its access will always require a specific decision and that such a decision could be delayed until well after the end of the waste emplacement operations. Under such circumstances, the incremental process leading to the implementation of the geologic disposal strategy incorporates the advantages of a temporary storage phase without letting this phase extend indefinitely.

The principle of sustainable development requires a balance between the needs of present and future generations. In this context, many countries favor a stepwise approach to repository development, whereby the present generation establishes a facility for long-term management of the waste while allowing future generations the option of adopting different management strategies if they wish.

4.7 Other Options

4.7.1 Deep Borehole Disposal

Disposal into very deep boreholes (>2 km) may be suitable for HLW where a relatively small volume of material requires disposal (see Fig. 13a). Unlike disposal in a repository, it would not require large volumes of rock to be excavated so that there might be fewer disturbances to the surrounding host rock. The main disadvantage of this method is the nonphased approach and the lower levels of waste retrievability. The end result of this method would, nonetheless, be broadly similar to phased deep geological disposal.

4.7.2 Direct Injection

This concept involves the injection of liquid radioactive waste directly into a layer of rock deep underground chosen to have suitable characteristics to trap the waste (i.e., minimize any further movement following injection) (see Fig. 13b). This process has been practiced in Russia.

4.7.3 Rock Melting

This concept involves the melting of wastes in the adjacent rock to produce a stable immobilized mass encapsulating the waste (see Fig. 13c). This technique has been mainly suggested for heat-generating wastes such as HLW and host rocks with suitable characteristics to reduce heat dissipation. The HLW in liquid or solid form could be placed in an excavated cavity or a deep borehole. The heat generated by the wastes would then accumulate, resulting in temperatures great enough to melt the surrounding rock and dissolve the radionuclides in a growing sphere of molten material. As the rock cools, it will crystallize and immobilize the radionuclides in the rock matrix. After complete crystallization and cooling, it is estimated that the waste would be strongly diluted (i.e., dispersed throughout a large volume of rock).

4.7.4 Ice Sheet Disposal

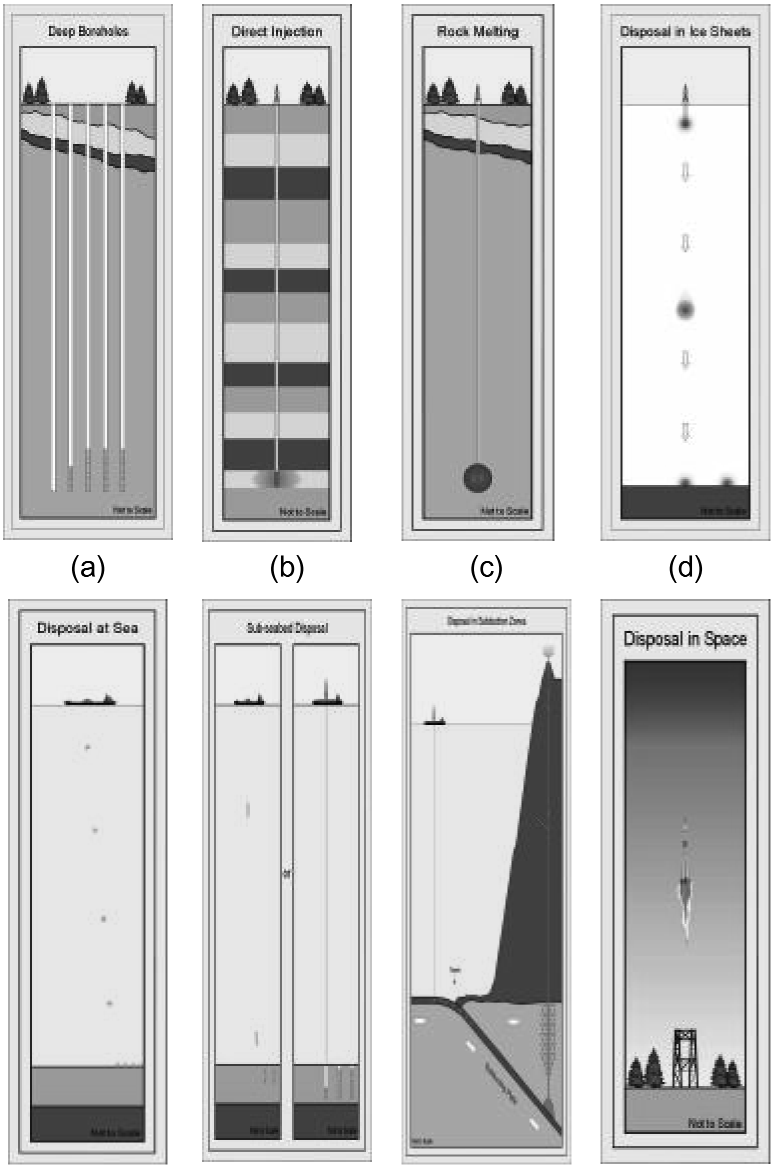
Disposal of spent nuclear fuel in ice sheets has also been suggested in the past and may be feasible, though it has not been extensively researched (see Fig. 13d). The idea has the advantage of placing the waste in a slowly changing environment, devoid of living organisms. Greenland and Antarctica are the only locations with sufficiently large ice sheets, and the latter is precluded by international treaty.

4.7.5 Sea Disposal

Historically, some countries (e.g., Belgium, the Netherlands, and the United Kingdom) have made use of sea disposal of solid radioactive wastes. However, this practice stopped in 1983. Sea disposal of solid wastes was achieved by simple dumping of waste packages on the seabed (see Fig. 13e). Other schemes envisage placing waste below the seabed in boreholes or through the use of free-falling penetrators dropped from the surface (see Fig. 13f). Areas could be chosen that were geologically stable and well removed from human habitation or important biological or mineral resources. A variant option would involve disposal into a subduction zone at a geologic plate margin (e.g., off the west coast of North America), where the relative motion of the plates would cause the waste to be carried down deep below the Earth's crust (see Fig. 13g). All these options are effectively ruled out by international agreements.

4.7.6 Disposal into Space

Disposing of used fuel by sending it into space has been considered and advocated in the past (Fig. 13h). Of all disposal methods, it has the greatest potential to isolate the wastes permanently from the biosphere. While technically possible, the costs of disposal in space would be very high. Studies have indicated that the number of flights required to transport high volumes of radwaste would be impractical; space disposal could be feasible only for the much smaller volumes of HLW. The risk of catastrophic accidents is estimated to be about 1% per flight, which suggests that the radiological risk of disposal in space may be unacceptably high.



(e) (f) (g) (h)

Fig. 13. Schematics of other waste management disposal options (courtesy of Nirex).

5. CURRENT WORLDWIDE STATUS OF DISPOSAL

5. CURRENT WORLDWIDE STATUS OF DISPOSAL

5.1 Introduction

Most countries using nuclear power have well-developed strategies for radioactive wastes, and there are many similarities between the programs of different countries. Rather than provide details of the various disposal programs, which by their nature are ever changing, we would encourage the reader to visit the Websites listed earlier and also the WasteLink Website at www.radwaste.org as a starting point.

The amount of waste held by any one country will obviously depend on the extent to which that country has exploited nuclear materials. Some of the oldest wastes relate to extraction of radium from uranium for medical purposes. In relation to electricity-producing nuclear reactors, an important aggravating factor is the propensity of early reactor designs to produce much more waste (per unit of electricity generated) than more recent ones. In general, however, the volume and the diversity of the wastes in a country's possession will depend on decisions taken by both past and present national governments in relation to policies for energy and defense. Important examples of such decisions are the extent to which nuclear power is to be used for electricity production, whether uranium mineral reserves are to be exploited, and whether spent nuclear fuel is to be treated as a waste or as a resource, as discussed in earlier sections. For reasons such as these, different countries face quite different challenges in terms of the quantity and the range of waste types that need to be managed.

5.2 Storage Facilities

Provided that the infrastructure, resources, and technology that created the wastes are largely still in place, storing these wastes to provide adequate protection to the current generation (short-term management) is relatively straightforward. Many waste storage facilities exist, and their construction and operation are considerably less complicated than, for instance, a nuclear power station or a reprocessing plant (see Fig. 11, for example).

5.3 Near-Surface Disposal

The radioactivity of wastes suitable for disposal in shallow trenches or engineered structures (see Fig. 14) will decay to harmless levels in 200 to 300 years. Such wastes are low-level and short-lived intermediate-level wastes (30 years or less half-life and maybe very low concentrations of long-lived materials). The design of the trenches and structures reflects the need to provide an adequate degree of isolation, depending on the level of radioactivity associated with the particular types of waste.

Fig. 14. Disposal vaults at Centre de l'Aube (courtesy of ANDRA).

Where it is relatively easier to do so, some countries have chosen to put these wastes in mined facilities—several tens of metres below ground—such as in Finland and Sweden (see Fig.15). The Swiss concept for low- and intermediate-level waste is to emplace it within a mountain horizontally accessible.

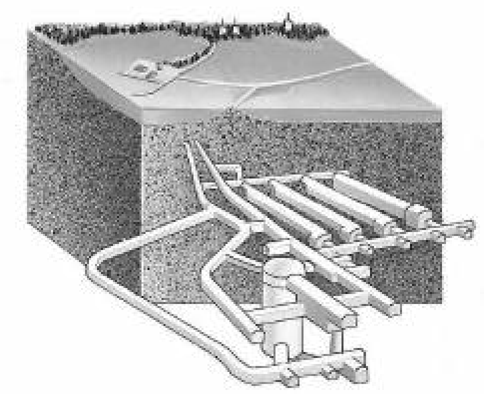


Fig. 15. Schematic of Forsmark low- and short-lived intermediate-level waste repository (courtesy of SKB).

5.4 Deep Disposal

Deep disposal of TRU waste has been taking place in the WIPP facility since March 1999. The only other deep facility to have operated is the Morsleben repository in Germany, but this was for low- and intermediate-level wastes and is now closed, although some disposals did take place at the Asse salt mine in Germany. Also in Germany, the Konrad repository for non-heat-generating wastes was licensed in 2002, but it has yet to take any waste.

Table 3 provides a summary of the latest information on disposal (as of August 2002) for many countries with nuclear programs.

Table 3.
Summary of International Practice

Country	Low-Level / Short-Lived Intermediate - Level Facility	Long-Lived ILW / HLW / Spent Nuclear Fuel Deep Facility
Australia	Site selection started	Not applicable
Belgium	Options being discussed with several local communities	Investigations at Mol deep URL, but site not yet chosen. Interested in pursuing international option
Canada	Options for historic waste being discussed at two communities – Port Hope and Port Granby	Siting program stalled
Czech Republic	Three repositories in operation: Dukovany, Richard, and Bratrství	Some siting studies taking place
Germany	LILW disposed of in former East German deep repository of Morseleben (now closed)	Some test disposal carried out at Asse Mine in the past Konrad facility for non-heat-generating waste licensed in 2002 Investigations at Gorleben facility in suspension
Finland	Operation LILW disposed of in mined facilities under Olkiluoto and Loviiisa NPPS	Site chosen near Olkiluoto for investigation by Posiva.
France	Centre de la Manche (now closed) Centre de l'Aube operational since 1992 VLLW facility being planned	URL investigations at Bure aimed at Parliamentary decision on options in 2006
Korea	In abeyance	

Table 3. (cont'd.)
Summary of International Practice

Country	Low-Level / Short-Lived Intermediate – Level Facility	Long-Lived ILW / HLW / Spent Nuclear Fuel Deep Facility
Hungary	Püspökszilágy since 1976. Site selection for new facility commenced in 1993	Siting for deep facility in progress
Italy	Siting for LILW facility being discussed	Siting for storage facility being discussed
Netherlands	Storage of all classes of waste at Vlissingen. Disposal decision deferred for 100 years.	
Japan	Rokkasho-Mura facility operational	Siting program starting. URL investigations also taking place
Russia	RADON facilities in operation	Studies taking place in Novaya Zemlya
Slovenia	Decisions not yet taken - pending discussion with Croatia	
Spain	El Cabril facility in operation since 1992	Site selection program in abeyance
Sweden	Forsmark mined facility in operation	Investigations under way at several sites
Switzerland	Wellenberg site had been chosen; following September 2002 referendum, it was abandoned	Investigations in north of country but no site selected. Interested in pursuing international option.
Taiwan	Facility in operation on island of Lan Yu	Some siting studies.
United Kingdom	BNFL's national Drigg facility in use since 1959. UKAEA local facility at Dounreay. Both for LLW only	Government consultation in progress on options. This follows failure of ILW siting program in 1997
United States	Several facilities at DOE sites for defense LLW. Barnwell and Hanford	WIPP for TRU waste in operation Yucca Mountain, Nevada, under investigation

6. INTERNATIONAL COOPERATION

6. INTERNATIONAL COOPERATION

6.1 Technical, Scientific, and Infrastructure Cooperation

6.1.1 Introduction

As noted elsewhere in this publication, there are many similarities between the ways in which different countries undertake the management and disposal of their radioactive waste. There is, therefore, extensive collaboration and exchange of information between countries to keep abreast of each other's programs, share knowledge, broaden experience, develop policies and strategies, and maximize the benefits of research and development (R&D).

Multinational projects include the following:

1. studies of the effects of tunnel excavation in underground laboratories
2. validation and verification of computer models
3. development of computer models of the transfer and accumulation of radioactive materials in the environment
4. studies of locations where natural radioactivity is already high or where hydrologic environments are similar to those expected in repositories
5. studies of gas generation and migration
6. groundwater movement studies
7. studies of mineralization of radionuclides in cement.

6.1.2 Underground Research Laboratories

Underground research laboratories (URLs) (see Fig. 16) provide facilities where geological, engineering, and other studies can be carried out at depth. Examples fall into two types: generic, where there is usually no intention to develop a repository; and site specific, where investigations are focused on investigating the suitability of the host rock as a potential repository. Most URLs involve (or have involved) international cooperation between waste management agencies and other organizations, such as the following:

1. SKB's Äspö hard rock laboratory, Sweden
2. Atomic Energy of Canada Ltd's (AECL) underground research laboratory, Whiteshell, Manitoba, Canada
3. NAGRA's URL at Grimsel (Fig. 16) and Mont Terri in Switzerland
4. ANDRA's URL under construction at Bure in France

5. Yucca Mountain Experimental Studies Facility in Nevada
6. facilities within the WIPP repository in Carlsbad, New Mexico
7. Tono in Japan
8. Mol facility in Belgium.

Fig. 16. Grimsel URL (courtesy of NAGRA).

6.1.3 European Union Sixth R&D Framework Program

The EU operates framework programs for shared-cost radioactive waste R&D. The Sixth R&D Framework Program was launched in 2002. See http://europa.eu.int/comm/research/fp6/index_en.html.

6.1.4 Policy and Infrastructure Cooperation

Club of Agencies

The Club of Agencies is an informal gathering of all of the national radioactive waste management organizations of the EU and applicant countries, with the EC providing the secretariat. The group meets about twice each year and provides an opportunity for the members to discuss the relative progress of national programs and policies and specialist topics.

Assistance to Central and Eastern Europe

Cassiopee is a consortium of EU radwaste agencies established in February 1993 to assist countries of Central and Eastern Europe in developing radioactive waste management systems. This is done within the EU's assistance programs: PHARE and TACIS. Its membership comprises ANDRA, COVRA, DBE, ENRESA, ONDRAF, and Nirex.

One of the first tasks undertaken by the consortium in 1993 was a one-year-long study of major importance to the respective countries. Since that time, priorities have been addressed, and Cassiopee's work has led to the establishment of new radwaste agencies in a number of countries.

EDRAM

EDRAM is an acronym for the Environmental Disposal of Radioactive Materials. It was established in Switzerland with membership comprising the waste management organizations of

1. Belgium, represented by NIRAS/ONDRAF
2. Canada, represented by OPG
3. Finland, represented by Posiva
4. France, represented by ANDRA
5. Germany, represented by BfS and DBE
6. Japan, represented by NUMO
7. Spain, represented by ENRESA
8. Sweden, represented by SKB
9. Switzerland, represented by NAGRA
10. United Kingdom, represented by Nirex
11. United States, represented by DOE.

High-level officials from the members meet at least annually to exchange information on strategic issues and specialist topics, such as the stepwise process and other waste management options.

6.1.5 The Work of IAEA

Much of the information in this publication has referred to the IAEA. The IAEA undertakes coordinated research; e.g., the BIOMASS program produces safety standards for radioactive waste under the RADWASS program. All of these activities bring together experts from many countries.

6.1.6 OECD Nuclear Energy Agency

The NEA is an agency of the OECD (see www.nea.fr). Membership currently consists of all EU member countries as well as Australia, Canada, Czech Republic, Hungary, Iceland, Japan, Republic of Korea, Mexico, Norway, Slovak Republic, Switzerland, Turkey, and the United States.

The primary objective of the NEA is to promote cooperation among the governments of its participating countries in furthering the development of nuclear power as a safe, environmentally acceptable and economical energy source. This is achieved by

1. encouraging harmonization of national regulatory polices and practices, with particular reference to the safety of nuclear installations, protection of humans against ionizing radiation, preservation of the environment, radioactive waste management, and nuclear third-party liability and insurance
2. assessing the contribution of nuclear power to the overall energy supply by keeping under review the technical and economic aspects of nuclear power growth and forecasting demand and supply for the different phases of the nuclear fuel cycle
3. developing exchanges of scientific and technical information, particularly through participation in common services
4. ensuring that appropriate technical and economic studies on nuclear energy development and the fuel cycle are carried out

5. setting up international R&D programs and joint undertakings.

In these and related tasks, the NEA works closely in collaboration with the IAEA, with which it has concluded a cooperation agreement, as well as with other international organizations in the nuclear field.

The NEA exists to promote cooperation among member states in furthering the development of nuclear power. Within the NEA, the Radioactive Waste Management Committee (RWMC) considers radioactive waste disposal issues and has focused increasingly on the selection and evaluation of potential disposal sites.

6.2 Multinational Radioactive Waste Facilities

6.2.1 General

The issue of the development of multinational facilities is quite topical and controversial and inspires many debates in a number of international forums and conferences. The IAEA has produced a document on the subject.[6] The information that follows is taken primarily from that document, which covers the main issues involved.

As described throughout this publication, most countries with radioactive waste have developed national strategies for its management. Most recognize that cooperation on multinational facilities is politically difficult, and the principle that a country or community that enjoys the benefit of nuclear energy should also carry the burden of managing the radioactive waste—the principle of proximity.

However, several examples can be given of international cooperation in waste disposal. Some countries have accepted responsibility for and the custody of waste generated in other countries. For example, spent-fuel-reprocessing contracts did not originally contain clauses on the return of reprocessing waste to the country of origin. Other examples are the return of U.S. enriched spent research reactor fuel to the United States (a practice that was discontinued in 1988 and has recently been resumed) and the return to the former USSR of commercial spent fuel of USSR origin.

The subject has also been debated extensively within the RWMC of the OECD/NEA. Preliminary studies on waste equivalence, which is an important issue if swaps or exchanges of waste are envisaged, were performed under the auspices of the EC. Several (IAEA) member states already expressed interest in this concept, and it is, therefore, proposed that the IAEA assess the many factors involved in such a concept.

Multinational repository means a disposal facility in a country (host country or host) that is used for the disposal of radioactive waste generated in several countries (partner countries or partners). Such a repository could be operated and managed by the host country or by a multinational consortium. (See www.arius-world.org.)

For obvious reasons of transportation distance and specific interests, the concept might apply, in the first place, to geographically grouped countries. A multinational repository is most likely to be located in a volunteering host country. This country must also be able to demonstrate an adequate level of technological skills, resources, and commitment for implementation.

One important reason for considering multinational repositories is that some countries generate such small volumes of some types of waste that it would be economically unreasonable to attempt final disposal in these countries. Costs for site selection, site characterization, and establishment and licensing of the repository would be disproportionate with regard to the size of the nuclear program. A multinational repository could offer a substantial benefit to these countries.

Regional collaboration for the disposal of LILW from the use of radioisotopes and irradiation sources may also be justified.

6.2.2 Scenarios of Cooperation

The following scenarios envisaged by the IAEA describe typical situations from which a multinational repository might develop:

1. Scenario I—Several industrialized countries with relatively small nuclear energy programs decide to cooperate for the disposal of their nuclear fuel waste.
2. Scenario II—A country with a large nuclear energy program offers disposal services to other countries with a limited production of radioactive waste.
3. Scenario III—Countries with small nuclear energy programs in varying stages of development seek assistance from each other. Among other issues is that of finding a suitable and common disposal option. This scenario is intended to assist countries whose sole use of nuclear materials is in the industrial, research reactors, or medical arena. While a repository dedicated solely to the disposal of medical waste and spent radiation sources could be constructed, it seems possible and preferable to handle these materials as part of a larger waste disposal project.
4. Scenario IV—A country without any nuclear expertise offers land for the disposal of radioactive waste to nuclear energy countries. In this scenario there is no expertise available in the country offering its disposal services. It could violate existing agreements such as the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, which prevents transboundary movements of radioactive waste in countries that lack the necessary infrastructure to properly manage the waste.

5. Scenario V—Specializing of national repositories for specific types of waste and international exchanges. Given local geological conditions, exchanges of waste types, preferably on a basis of mutual equivalence, can be envisaged. A good example could be the exchange of heat-generating HLW against non-heat-generating TRU.

6.2.3 Public Involvement

Past experience indicates that establishing a radioactive waste repository is as much a political as a technical undertaking. Thus, the public sentiment of a host country must be assessed along with its geologic suitability. Countries considering a multinational repository must have confidence that the host country can sustain public acceptance of the facility. Assurances regarding the safe transport and management of all waste materials, monetary incentives, and a meaningful and well-defined public participation program could all be addressed in negotiations among partners to foster continued public support among host country citizens.

6.2.4 Conclusion

Reference 5 examines many rational arguments and potential benefits for the development and implementation of multinational repositories. However, one should also be aware of the many political and public acceptance issues that may arise in opposition to the multinational concept. A prerequisite for such an approach is the achievement of consensus among the relevant countries and regions, in particular regarding the transboundary movement of radioactive waste. In this context, many countries are concentrating their efforts on demonstrating the feasibility of safe disposal in their own country. Such a step could be a prerequisite to future negotiations on the implementation of multinational repositories.

7. INTERNATIONAL INSTRUMENTS

7. INTERNATIONAL INSTRUMENTS

7.1 General

Broadly speaking, four international organizations contribute to the development and statement of principles for radioactive waste management. They are

1. IAEA
2. ICRP
3. OECD - NEA (discussed in Sec. 6)
4. EU

7.1.1 *The International Atomic Energy Agency*

The IAEA (www.iaea.org) was established by the United Nations in 1957 to ensure world cooperation for the peaceful use of nuclear energy. It has some 113 member countries and is responsible for the prevention of the diversion of nuclear materials to weapons production. In addition, the IAEA has also been responsible for the development of safety guidelines in relation to the key components of the nuclear cycle. These are set out in a series of color-coded documents.

While IAEA guidelines and regulations have no legal jurisdiction, in practice, member countries usually comply with their recommendations. As a multilateral international organization, the IAEA's influence is considerable because of its relationship with the World Bank and so forth. Because these multilateral organizations tend to work together, few countries risk souring relations with any particular agency.

7.1.2 International Commission on Radiological Protection

Radiological protection dates back to the early years of medical uses of radiation and radioactive materials, with various countries introducing protection rules during the first few decades of the 20th century. Since 1928, the ICRP (www.icrp.org) has published universal recommendations, regularly updated in the light of recent information, on the effects of radiation exposure on health. The ICRP is an independent body of medical and scientific experts.

7.1.3 European Union

Recommendations made by the ICRP, IAEA, and OECD-NEA form the basis of specific European Community directives issued by the EC (www.europa.eu.int). The principles, standards, and requirements relating to nuclear and environmental matters in all member states of the EU are based on the Treaty of the European Atomic Energy Community (Euratom) of 1957, the Treaty of the European Economic Community (EEC) of 1957, and the Single

European Act of 1987. They are implemented in accordance with the requirements of these treaties, through formal and binding regulations, directives, and decisions.

7.2 Specific Examples of Treaties and International Legislation

This section is only intended to show examples of a number of international instruments. It cannot be regarded as fully comprehensive. For further information, the reader is encouraged to visit the legal section of the NEA Website at www.nea.fr.

7.2.1 European Union

Euratom Treaty Article 37

Member states are required to provide the EC with such general data relating to any plan for the disposal of radioactive waste as will make it possible to determine whether the implementation of such a plan is liable to result in the radioactive contamination of another member state.

Basic Safety Standards Directive 96/29 (Euratom)

This directive lays down basic safety standards for the protection of the health of workers and the general public against the dangers of ionizing radiation.

1991 Convention on Environmental Impact Assessment in a Transboundary Context

This convention was agreed to in Espoo, Finland, in 1991 under the aegis of the U.N. Economic Commission for Europe, whose members include European countries, Canada, and the United States. This convention seeks to control adverse transboundary environmental impact of activity and enhancement of international cooperation in assessing environmental impact in a transboundary context.

EC Directive 85/337/EEC (as amended by 97/11/EC) on Environmental Assessment

The requirements for environmental impact assessment (EIA) within the EU are set out in Council Directive 97/11/EC of March 3, 1997, amending Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment. A consolidated version of the amended directive is also available on the EU Website at http://europa.eu.int/comm/environment/eia/full-legal-text/9711_consolidated.pdf.

The amended EIA directive predates the U.N. Economic Commission for Europe's 1998 Convention on Access to Information, Public Participation in Decision-Making, and Access to Justice in Environmental Matters, generally known as the Aarhus Convention. This convention has significant implications for the directive because it contains stricter public participation provisions and has been signed by the EU as well as the individual member states and most of the applicant countries. A proposal for a directive of the European Parliament and of the council amending a number of directives, including the EIA directive, has been published.

7.2.2 International Rules On Sea Disposal

London Dumping Convention 1972

The London Dumping Convention originally adopted a global ban on the dumping at sea of only high-level radioactive wastes. In 1983, this was extended by a conference resolution to a moratorium on the dumping at sea of all radioactive wastes. In 1985, the duration of the moratorium was extended indefinitely. In November 1993, the parties to the convention adopted permanent amendments to Annex 1 prohibiting the dumping of all radioactive wastes at sea.

U.N. Conference on Environment and Development Agenda 21

This document has no legal effect. It does, however, represent a significant advance in international cooperation in the implementation of global environmental policies. It was adopted by consensus at the U.N. Conference on Environment and Development in Rio de Janeiro, Brazil, in 1992. It sets out an environmental action plan for sustainable development and seeks support for the safe and environmentally sound management and disposal of radioactive wastes.

> Paragraph 22.5 (c) states:
>
> States... should:... not promote or allow the storage or disposal of high-level, intermediate-level and low-level radioactive wastes near the marine environment unless they determine that scientific evidence, consistent with the applicable internationally agreed principles and guidelines, shows that such storage or disposal poses no unacceptable risk to people and the marine environment... .

The Convention for Protection of the Marine Environment of the North East Atlantic (OSPAR)

The 1992 OSPAR Convention, when ratified, will replace the 1972 Oslo and 1974 Paris Conventions. The convention bans the disposal at sea of all low- and intermediate-level radioactive wastes, but includes an option for France and the United Kingdom to resume the practice, subject to certain conditions, after a period of 15 years from January 1993. The United Kingdom has indicated that it intends to give up its option. (See www.ospar.org.)

U.N. Law of the Sea Convention 1982

The U.N. Law of the Sea Convention imposes a very broadly expressed duty on states:

> States shall take all measures necessary to ensure that activities under their jurisdiction or control are

so conducted as not to cause damage by pollution to other States and their environment...(Article 194 (2))

7.2.3 International Convention on the Safety of Spent-Fuel and Radioactive Waste Management

This convention was negotiated under the aegis of the IAEA and is now open for signature and ratification.

It reaffirms the importance to the international community of ensuring that sound practices are planned and implemented for the safety of spent-fuel and radioactive waste management. Its objectives are

1. to achieve and maintain a high level of safety worldwide in spent-fuel and radioactive waste management through the enhancement of national measures and international cooperation, including where appropriate, safety-related technical cooperation
2. to ensure that during all stages of spent-fuel and radioactive waste management, there are effective defenses against potential hazards so that individuals, society, and the environment are protected from harmful effects of ionizing radiation, now and in the future, in such a way that the needs and aspirations of the present generation are met without compromising the ability of future generations to meet their needs and aspirations
3. to prevent accidents with radiological consequences and to mitigate their consequences should they occur during any stage of spent-fuel or radioactive waste management.

The convention contains requirements regarding such matters as general safety, siting of facilities, design and construction of facilities, safety assessment, environmental assessment, operational controls, regulatory bodies and licensing, decommissioning, and transboundary movement.

7.2.4 International Treaties and Conventions on Transboundary Shipments of Radioactive Waste

The Fourth ACP-EEC Convention (Lomé Convention)

This convention was signed at Lomé, in Togo, in December 1989 and was approved by the EC in February 1991. ACP refers to 69 countries in the African Caribbean and Pacific regions, mostly former colonies of European countries. Article 39 states:

> The Community shall prohibit all direct or indirect export of hazardous waste or radioactive waste to the ACP States, while at the same time the ACP States shall prohibit the direct or indirect import into their territory of such waste from the Community or from any other country, without prejudice to specific international undertakings to which the contracting parties have subscribed or may subscribe in the future in these two areas within the competent international fora. These provisions do not prevent a Member State to which an ACP State has chosen to export waste for processing from returning the processed waste to the ACP State of origin.

The Bamako Convention

In 1991, the Organisation of African Unity adopted the Bamako Convention on the ban of the import into Africa and the control of transboundary movement and management of hazardous wastes within Africa. This convention is closely modeled on the Basel Convention, but unlike the Basel Convention, it also applies to U.N. waste stream YO, “all wastes containing or contaminated by radionuclides, the concentration or properties of which result from human activity.”

Directive 92/3/Euratom on the Supervision and Control of Shipments of Radioactive Wastes Between Member States and into and out of the European Community

This directive applies to shipments of radioactive waste, as defined, between member sates and into and out of the European Community whenever the quantities and concentrations exceed the levels laid down. Specific provisions apply to the reshipment of radioactive waste. The directive came into force on January 1, 1994. Article 11 states:

The competent authorities of Member States shall not authorise shipments:

1. either to:
   - (a) a destination south of latitude 60° south;
   - (b) a State party to the fourth ACP-EEC Convention which is not a member of the Community, taking account, however of Article 14; (permitting return of wastes to country of origin after reprocessing);
2. or to a third country which, in the opinion of the competent authorities of the country of origin, in accordance with the criteria referred to in Article 20, does not have the technical, legal or administrative resources to manage the radioactive waste safely.

REFERENCES

1. *The Principles of Radioactive Waste Management,* Safety Series No. 111-F, International Atomic Energy Agency (1995).

2. *Classification of Radioactive Waste, A Safety Guide,* Safety Series No. 111-G-1.1, International Atomic Energy Agency (1994).

3. *Establishing a National System for Radioactive Waste Management,* Safety Series No. 111-S-1, International Atomic Energy Agency (1995).

4. *Future Financial Liabilities of Nuclear Activities,* Organization for Economic Cooperation and Development (1996).

5. W. Miller et al., *Geological Disposal of Radioactive Wastes and Natural Analogues,* Waste Management Series, Vol. 2, Pergamon Press (2000).

6. "Technical, Institutional and Economic Factors Important for Developing a Multinational Radioactive Waste Repository," TECDOC-1021, International Atomic Energy Agency (1998).