Radioactive waste management: An international perspective

A report on national policies and practices in the context of ongoing research, development, and demonstration around the world

by Candace Y. Chan

Scientists, governments, and the general public have devoted considerable attention to the subject of radioactive waste over the past 35 years. The subject has gained even more attention of late, owing to heightened awareness of environmental protection. Potential transboundary effects have further added to this interest, which today extends beyond local domains to regional and global levels.

Almost all of the IAEA's Member States generate some radioactive wastes. The type of waste they produce varies, however, as do the quantities, which range from a few grams to several hundred tonnes of wastes per year.

This article will summarize the status of waste management and disposal activities in IAEA Member States as well as providing a brief background on what radioactive waste is, where it comes from, and how it is managed.

National policies and practices

Low- and intermediate-level wastes (L/ILW). For this category of wastes, minimization is the current emphasis in most national programmes. Increases in the cost of radioactive waste disposal over the past decade have resulted in a substantial, and generally successful, effort by waste generators to reduce the volume of radioactive wastes at the point of, and after, generation. *(See tables, pages 13 and 14.)*

LLW and ILW disposal. The disposal of low- and some intermediate-level waste has been practiced in several countries for over the past 30 years. At present, countries are continuing to rely on a mix of near-surface and subsurface disposal facilities for disposal of L/ILW, but with increased reliance on the use of engineered barriers to isolate the radioactive wastes. Also, some countries, because of lack of suitable near-surface locations, or for reasons of national policy, dispose of L/ILW at much greater depths. The Swedish Final Repository (SFR), which became operational in 1988, is an example of such a facility. The SFR, located at Forsmark, is constructed in rock caverns approximately 60 meters below the sea-bed with access from land.

During the past 2 years, several new low-level disposal facilities have received authorization for construction and/or operation. For example, at the end of 1991, the Centre de L'Aube in France received its authorization for operation and earlier this year received its first shipment of waste for disposal. In Spain, the El Cabril LLW disposal site, and in the United States, the Ward Valley, California LLW disposal site are also ready to begin operation once they receive the necessary regulatory authorizations. In Finland, the VLJ final repository for reactor waste, on Olkiluoto Island, began operation this year.

High-level waste and spent fuel. By the turn of the century, around 200 000 tonnes of spent oxide fuel will have been discharged from nuclear power reactors operated around the world. The choice between direct disposal and the reprocessing of spent fuel depends on a number of factors including economic, political, and energy policy considerations.

At present direct disposal is planned for much of the spent nuclear fuel. *(See table, page 12.)* In particular, Canada, Finland, Spain, Sweden, and the United States are all considering spent fuel disposal. Argentina, Belgium, China, France, Italy, Russia, Switzerland, and the United Kingdom are in favour of the reprocessing route. In Germany, only the reprocessing route is officially approved. However, consideration is being given to the concept of direct disposal.

All countries that are reprocessing spent fuel are planning to vitrify the high-level waste into a

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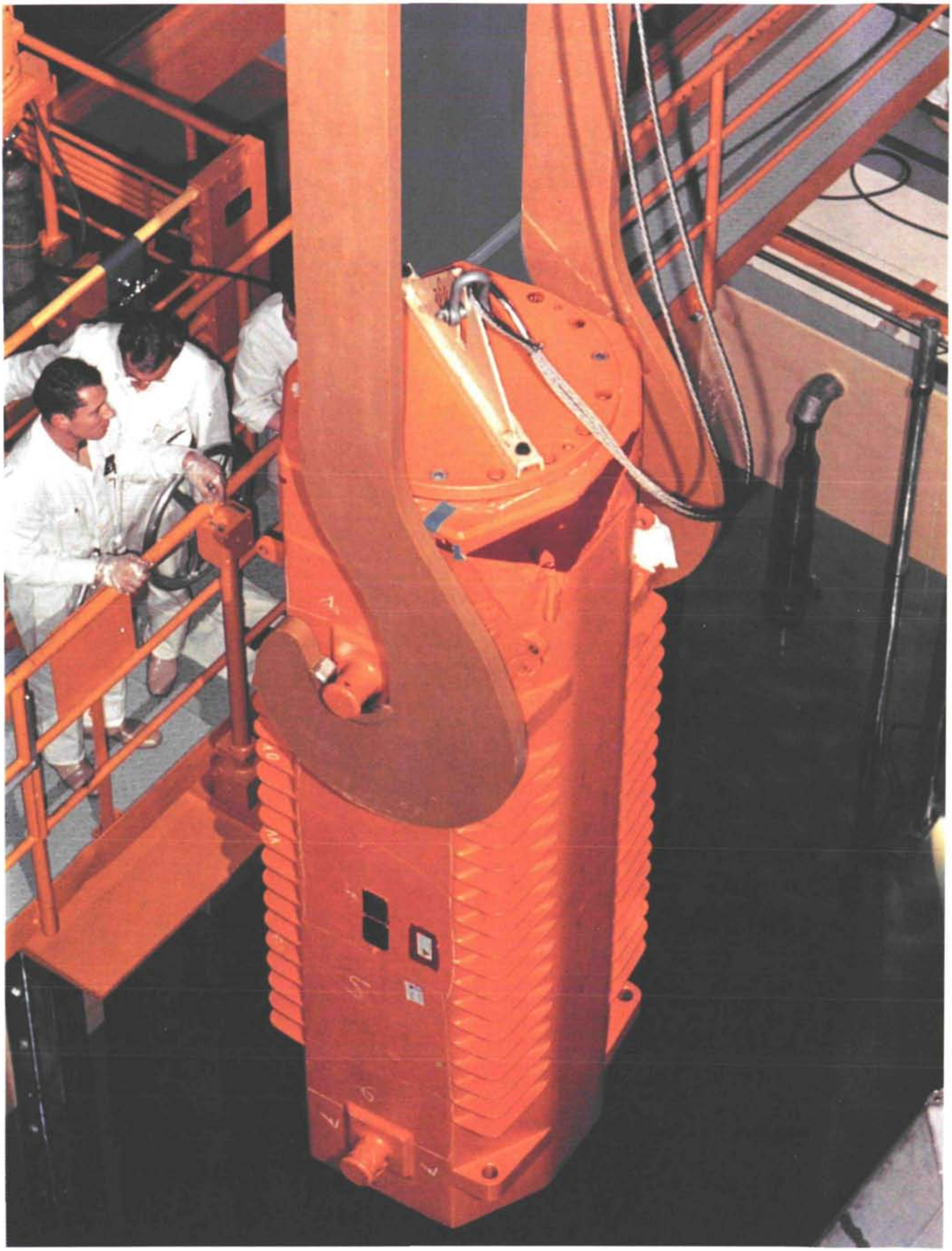
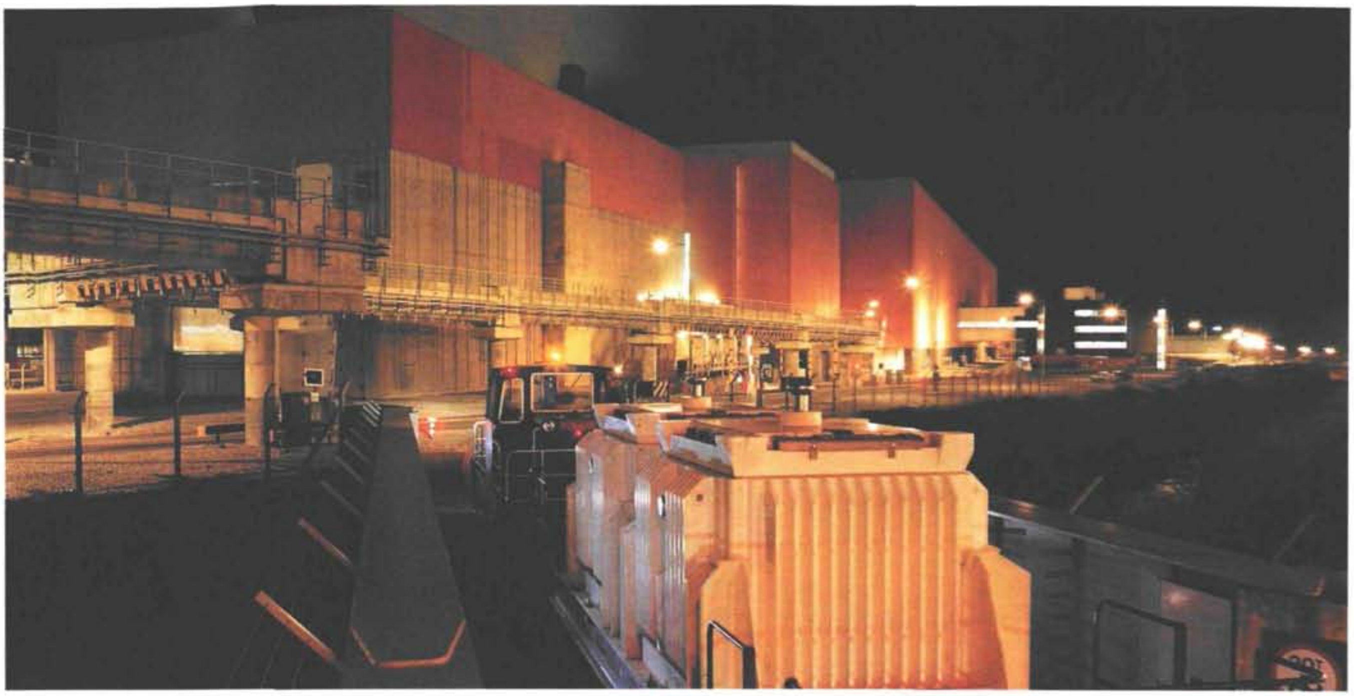
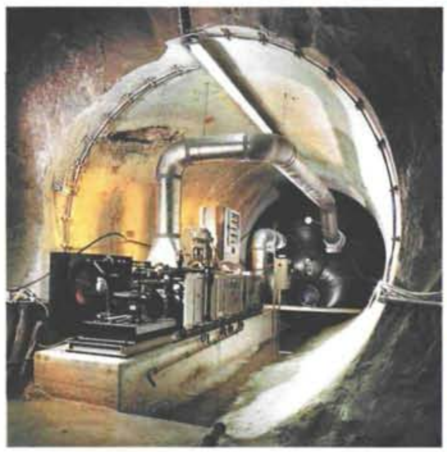
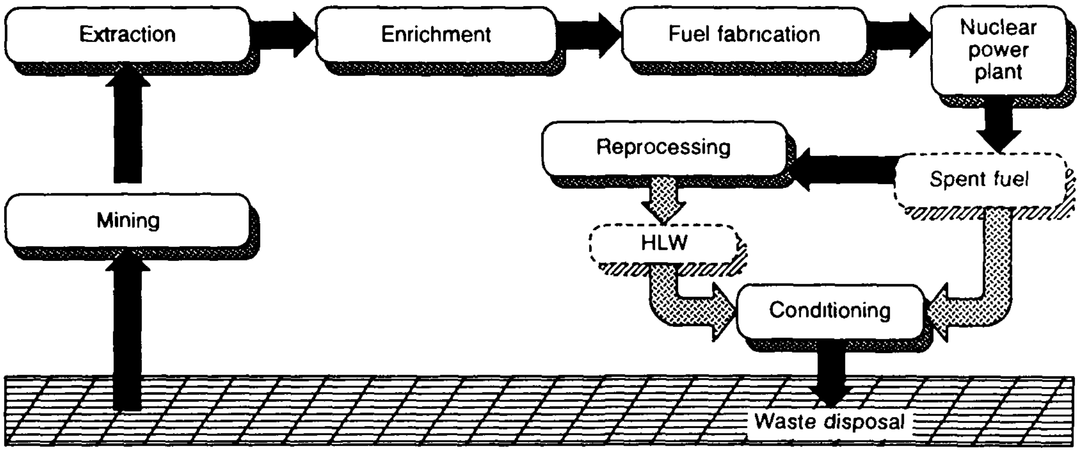






Facing page: A spent fuel cask being lowered into position at the nuclear research centre in Karlsruhe, Germany.
This page: *Top* — Flasks of spent fuel arriving at the Sellafield site in the United Kingdom for reprocessing. *Middle left* — Short-lived radioactive wastes being handled at the La Manche disposal centre in France. *Middle centre & right* — Researching radioactive waste disposal at at an underground test site in Switzerland. *At right* — Inside the storage chambers at the Swedish Final Repository in Forsmark. (Credits: KFZ, SKB, BNFL, Nagra)

A schematic of the nuclear fuel cycle



Origin and types of radioactive waste

Waste, whether it be from households or industries, is a natural part of everyday life. It is all around us — including waste products that we do not see, such as gaseous wastes released into the atmosphere. Waste is produced by every living thing and by most human endeavors, such as the generation of electricity, whether the energy source is coal, oil, or nuclear.

Where radioactive waste comes from

In general, the IAEA defines radioactive waste as "any material that contains or is contaminated with radionuclides at concentrations or radioactivity levels greater than the 'exempted quantities' established by the regulatory body and for which no future use is foreseen". Such waste comes from five main activities:

- ***Uranium and thorium mining and milling.*** Some16 countries have activities relating to the mining and refining of uranium and thorium ores.
- ***Nuclear fuel cycle operations such as uranium conversion and enrichment, fuel fabrication, and spent fuel reprocessing.*** As of 1991, 11 countries have operated demonstration or industrial-scale enrichment facilities, 19 have fabricated uranium oxide (UO_2) and/or plutonium oxide (PuO_2) fuels, and 15 are or are planning to reprocess spent nuclear fuel.
- ***Operations of nuclear power stations.*** As of the end of 1991, there were 420 nuclear power reactors in operation in 29 countries with a total capacity of 326 611 megawatts-electric.
- ***Decontamination and decommissioning of nuclear facilities.*** By the year 2000, approximately 64 nuclear power plants and 256 nuclear research reactors will be reaching 30 years of age.
- ***Institutional uses of isotopes.*** These activities are widespread and involve the use of radionuclides and radiation sources in medicine, research (including research reactors and test facilities), industry, and agriculture.

Though only a fraction of the IAEA's Member States are involved with all of the above activities, it is worthy to note that almost every Member State produces some radioactive wastes — if only from institutional uses of isotopes.

The waste resulting from the above activities comes in various forms (i.e., gaseous, liquid, or solid). These wastes have different characteristics. For safety and technical reasons, the various forms of wastes are usually categorized by their levels of radioactivity, heat content, and potential hazard.

All radionuclides have a **half-life** — a term which refers to the time it takes for any given radionuclide to lose half of its radioactivity. This means that radioactive waste eventually decays into non-radioactive elements (a positive point about radioactive materials). The predominate radionuclides in waste, which are highly radioactive, have half-lives of about 30 years or less; for example, caesium-137. A few, such as iodine-129, have half-lives in the millions of years. For perspective, uranium which naturally occurs in the earth has a half-life of about 4500 million years. In general, radioactive waste can be categorized into two general groups: **short-lived and long-lived wastes**. Wastes with half-lives longer than approximately 30 years are generally considered long-lived.

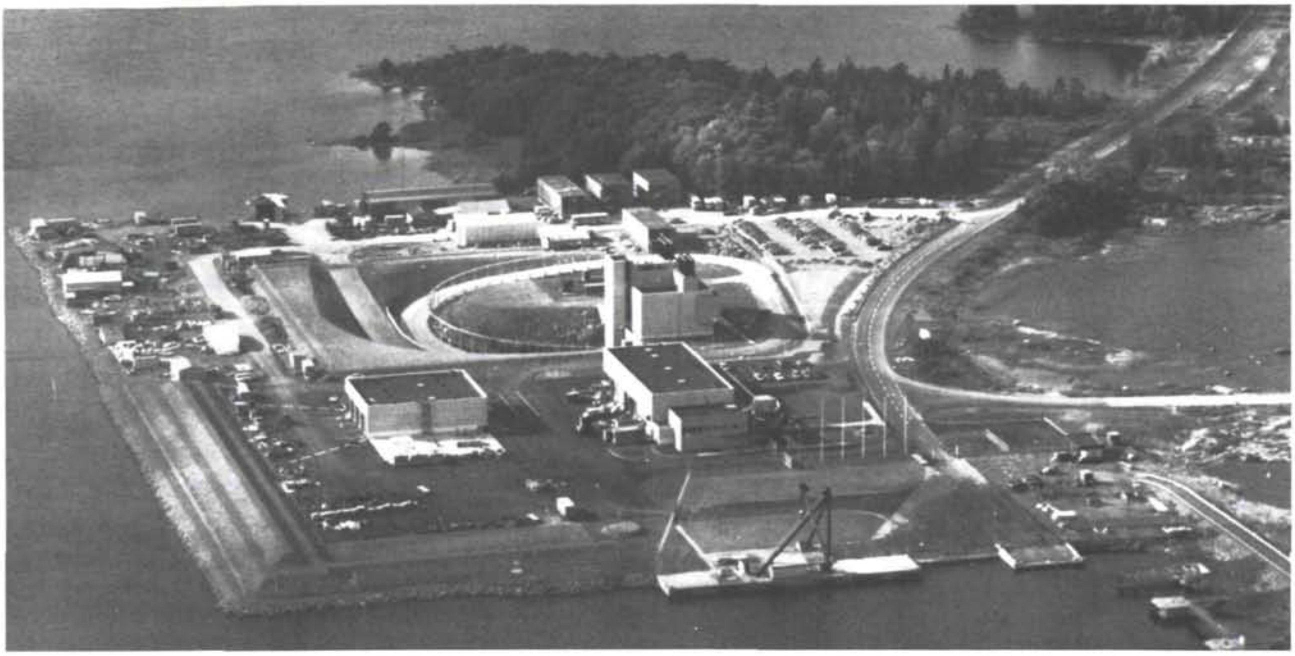
Categories of radioactive waste

The following definitions incorporate the technical features of radioactive wastes based on general characteristics with regard to disposal. The categories are as follows.

Low-level wastes (LLW) contain a negligible amount of long-lived radionuclides. Produced by peaceful nuclear activities in industry, medicine, research, and by nuclear power operations, such wastes may include items such as packaged gloves, rags, glass, small tools, paper, and filters which have been contaminated by radioactive material. Disposal in near-surface structures or shallow burial is practiced widely.

Intermediate-level wastes (ILW) contain lower levels of radioactivity and heat content than high-level wastes, but they still must be shielded during handling and transport. Such wastes may include resins from reactor operations or solidified chemical sludges, as well as pieces of equipment or metal fragments. Commercial engineering processes are being used to treat and immobilize these wastes. Disposal options are similar to those for low-level wastes.

High-level wastes (HLW) arise from the reprocessing of spent fuel from nuclear power reactors to recover uranium and plutonium. These wastes contain transuranic elements, and fission products that are



Aerial view of the Swedish Final Repository for radioactive waste at Forsmark.

highly radioactive, heat-generating, and long-lived. Liquid HLW usually is immobilized as a solid glass matrix and stored in interim storage facilities prior to final disposal and isolation in deep, stable geologic formations as currently planned by many national programmes. ***Spent nuclear fuel*** that is not reprocessed is also considered high-level waste.

Alpha bearing wastes (also called transuranic, plutonium-contaminated material, or alpha wastes) include wastes that are contaminated with enough long-lived, alpha-emitting nuclides to make near-surface disposal unacceptable. They arise principally from spent fuel reprocessing and mixed-oxide fuel fabrication. The wastes may be disposed of in a similar manner as HLW.

Although the above broad descriptions are used by many countries, it is important to note that there are also other accepted definitions in use.

What is radioactive waste "management"?

The IAEA defines radioactive waste management as: activities, administrative or operational, related to the minimization, handling, treatment, conditioning, transport, storage, and disposal of radioactive wastes. Though this definition may vary from country to country, scientists and engineers in the field agree that the overriding objective of radioactive waste management is to protect humans and their environment from the hazards arising from radioactive wastes — for the present and future.

As in many other processes, there are different approaches to waste management, but the IAEA term is referred to as the "systems approach". This refers to a logical, integrated strategy for determining the requirements, technology, resources, and impacts of a waste management system. This approach considers each aspect of the entire system — from point of generation to the final disposal of the waste.

Management and disposal of LLW and ILW. These types of waste are often treated (volume reduction) and/or conditioned (waste immobilization) prior to disposal. This area of LLW and ILW waste management, having been established and proven over the past 35 years, is considered to be quite matured in terms of technology development. As a result, several effective, safe, and feasible treatment and conditioning options exist for these types of wastes. They include: storage and decay, compaction and super compaction, incineration, chemical precipitation, evaporation, filtration, and ion-exchange; these may be followed by immobilization in materials like concrete, bitumen, or polymers.

The most common disposal methods for L/ILW involve disposal in shallow earthen or concrete lined trenches or in structures on the ground (commonly referred to as engineered surface facilities). Safe near-surface disposal of LLW has been practiced in a number of countries for almost 30 years. The rationale behind near-surface disposal is that the isolation period for this type of waste is relatively limited (up to 300 years) and, therefore, the institutional or administrative control of the disposal site can be assured.

Management and disposal of HLW and spent fuel. After its useful life, spent nuclear fuel is removed from the reactor. Once removed, it is usually placed into temporary on-site storage before it is either:

- placed in interim away-from-reactor storage (5-100 years), conditioned after a sufficient decay period, and stored before its eventual final disposal in a geologic repository; or
- reprocessed after additional away-from-reactor storage. The resulting liquid high-level waste, containing mostly fission products and a small proportion of the actinides, is then immobilized in a stable matrix (i.e., borosilicate glass), and would then be disposed of in a geologic repository.

Regardless of which option is chosen, there is broad scientific agreement that deep geologic disposal using a system of engineered and natural barriers to isolate these wastes is the preferred method for their disposal. ❐

High-level waste and spent fuel management plans in selected countries:

	Storage time (years)	Final waste form	Status	Geologic media
Argentina	20 or more	HLW	S	Granite
Belgium	50	HLW	U	Clay
Bulgaria	3	HLW SF*		
Canada		SF	U U	Granite Crystalline
Chile	10	SF		TBD
China	30-40	HLW	U U U	Granite Basalt Tuff
Cuba	10	SF		
Czechoslovakia	3-5	SF		
Finland	40	SF	U U	Granite Crystalline
France	30 or more	HLW	U U U U	Clay Granite Schist Salt
Germany	to 30	HLW	S	Salt
Indonesia	5 or more	SF	U U	Granite Crystalline
Italy	TBD	HLW SF	U	Clay
Japan	30-50	HLW	U U	Crystalline Sedimentary rock
Mexico	30	SF	U U U U U U U	Clay Granite Schist Crystalline Salt Sedimentary rock Tuff
Netherlands	50 or more 50 or more	HLW SF		
Norway	5-15	SF		TBD
Poland	30 3-5	HLW SF*		
Romania	2	SF		
South Africa	40	SF		TBD
Spain	30	SF	U U U	Clay Granite Crystalline
Sweden	40	SF	U	Crystalline
Switzerland	40	HLW	U U U	Clay Granite Sedimentary rock
United Kingdom	50	HLW		TBD
United States	5-10	SF	U	Tuff
USSR (former)	30 30-40	HLW SF	S U U U	Granite Crystalline Salt Tuff Clay

* *Spent fuel returned to supplier.*

Notes: HLW = High-level waste; SF = Spent fuel, S = Selected; U = Under investigation, TBD = To be determined.

Source IAEA Waste Management Database

solid monolithic borosilicate glass which has been demonstrated to have excellent chemical durability properties. Of those countries preferring direct disposal of conditioned spent fuel, Canada and Sweden are planning to incorporate their spent fuel within a matrix material of sand and copper or lead, respectively. Germany and the USA presently are not planning to use any matrix materials.

Belgium, France, Japan, Germany, Switzerland, and the UK all plan to use the French-type container for their borosilicate glass (stainless steel, with 5 mm wall thickness). The stainless steel container planned for use in the USA has a thicker wall (1 cm). The USA is also planning to use stainless steel canisters for the small quantity of vitrified civilian high-level waste, similar to the canister planned in most other countries. Thick-walled container concepts include the Swedish 10-cm-thick copper container and the German steel Pollux cask for spent fuel disposal. Germany plans to use a triple purpose package for spent fuel disposal, which includes a disposable transportation overpack. For solidified high-level waste, Switzerland and the USA are planning to use overpacks, and the UK will consider them in the future.

Normally, in the case of reprocessing, the spent fuel is placed in extended interim storage in the reactor storage pools (typically for up to 10 years) until the spent fuel is shipped to the reprocessing plant, which will also provide some interim storage in storage pools. In direct-disposal programmes, wet or dry interim storage methods are planned or already in use. Canada plans interim storage for its spent fuel at reactors (using both wet and dry storage methods) until disposal. Sweden is storing its spent fuel at reactors for a few years, followed by interim storage in its central away-from-reactor wet storage facility — CLAB. Switzerland and Germany are planning for some dry interim storage of spent fuel at one or more central locations, including away-from-reactor facilities, to supplement their at-reactor storage.

In most countries, the spent fuel and/or solidified high-level waste will be stored for approximately 20 to 100 years before disposal because no operational geologic repository is expected for at least the next 20 years. Countries that have (or are planning) spent fuel reprocessing are planning interim storage for their solidified high-level waste for at least 10 to 50 years — or even longer. In the UK, repository development is being deferred in favour of long-term storage, which may continue for as long as 100 years. It is expected that all interim storage of solidified high-level waste will employ dry storage concepts.

Transportation of radioactive waste

The transportation of radioactive materials is one of the most successful and proven transport systems in the world. Considering the great numbers of shipments around the world each year, this system has one of the best safety records of any industry. One reason for this success is the existence of international transportation regulations (i.e., IAEA transportation regulations) and codes as well as the high-level of co-operation among countries.

Most countries use single-purpose casks for transporting spent fuel and high-level waste. Several countries are developing and/or using dual purpose transportation and storage casks. Triple purpose (transportation, storage, and disposal) casks are being developed in Germany and Canada.

Safety assessment of waste repositories

Although the disposal of high-level waste has yet to be demonstrated, a considerable amount of research and development has been carried out in this area, including the development of underground laboratories and other near- and far-field test facilities. Results and studies have shown that deep geologic disposal of high-level waste and spent fuel, using the multiple barrier concept, is the most technically sound, feasible, and safest option available. The multiple barrier concept refers to a redundant system of barriers, both engineered and natural (geologic medium), that hinder the potential migration of radionuclides from the repository site.

In March 1991, after several years of development, an advisory group of experts from the IAEA and the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development presented a landmark document with the endorsement of the Commission of the European Communities. This document, called the Collective Opinion, is a statement regarding the status of scientific evaluation of radioactive waste repositories for high-level waste. It reaffirmed support for the geologic repositories approach. One important conclusion of the experts is that the appropriate use of safety assessment methods, coupled with sufficient information from disposal sites, can provide the technical basis to determine whether radioactive waste disposal systems would offer to society a satisfactory level of safety for both current and future generations.

The technology of deep geologic disposal is the subject of investigation in a number of national and international research and development

Storage and disposal of low- and intermediate-level wastes in selected countries of Africa, the Middle East and Europe:

	Storage time (years) and method		Status/disposal method	
Africa & the Middle East:				
Egypt	50	Engineered facility	P	Engineered surface facility
Jordan	10	Shallow land facility (planned)	P	Shallow land burial
South Africa	None		C	Shallow land burial
Syria	15	Shallow land facility	P	TBD
Zambia	NR	Engineered facility	P	Engineered surface facility
		Pit burial	C	Shallow land burial
Europe:				
Belgium	20-25	NR	P	Options studied
Bulgaria	NR	Shallow land facility	C	Shallow land burial
		Engineered facility	C	Engineered surface facility
Czechoslovakia	None	Shallow land facility	P	Engineered surface facility
			P	Shallow land burial
			C	Rock cavities
			P	Deep geological repositories
Finland	To 25	Engineered facility	P	Rock cavities
France	1	Engineered facility (on production site)	C	Engineered surface facility
			P	Shallow land burial
Germany	None	Engineered facility	C	Rock cavities
			P	Deep geologic repositories
Hungary	NR	Shallow land facility	C	Shallow land burial
Italy	NR	Engineered facility	P	Engineered surface facility
Netherlands	50 or more	Engineered facility	P	Deep geologic repositories
Norway	1-5	Engineered facility Shallow land facility	C	Shallow land burial
Poland	0-5	TBD, no storage planned for some wastes	C	Engineered surface facility
			P	Deep geologic repositories
Spain	NR	Engineered facility	P	Engineered surface facility
Sweden	1-10	Engineered facility	P	Shallow land burial
Switzerland	Minimum	Engineered facility	P	Deep geologic repositories
United Kingdom	None		C	Engineered surface facility
			P	Deep geologic repositories
USSR (former)	20 or more	Engineered facility	C	Engineered surface facility
			P	Shallow land burial
			P	Deep geologic repositories

Notes: C = Current practice; P = Planned practice; TBD = To be determined; NR= Not reported to the IAEA's Waste Management Database.

Source: IAEA Waste Management Database

Storage and disposal of low- and intermediate-level wastes in selected countries of North America, Latin America and Asia & the Pacific:

	Storage time (years) and method		Status/disposal method	
North America:				
Canada	NR	Engineered facility	P	Shallow land burial
Mexico	up to 10	Shallow land facility	C	Shallow land burial
		Engineered facility	P	Shallow land burial
United States	Mini-mum	NR	P	Engineered surface facility
			C	Shallow land burial
			P	Engineered subsurface
Latin America:				
Brazil	10	Engineered facility	P	Shallow land burial
Chile	30	Engineered facility (stored for decay)	C	Engineered surface facility
			C	Store for decayl
Cuba	10-15	Engineered facility	C	Engineered surface facility
			P	Shallow land burial
Asia and the Pacific:				
Australia	TBD	Temporary facility	P	Shallow land burial
China	5	Engineered facility	P	Shallow land burial
			P	Rock cavities
Indonesia	1-5 or more	Engineered facility Shallow land facility	P	Engineered surface facility
			P	Shallow land burial
			C	Dilute/disperse
Japan	310	Shallow land facility	P	Shallow land burial
			P	Sea dumping
Korea, Rep. of	1	Engineered facility	P	Rock cavities
Malaysia	30	Engineered facility	P	Engineered surface facility
Pakistan	up to 1 week	Liquid storage	C	Decay/discharge
			C	Shallow land burial

Notes: C = Current practice; P = Planned practice, TBD = To be determined, NR = Not reported to the IAEA's Waste Management Database.
Source. IAEA Waste Management Database

programmes. During the past 20 years, there have been many successful international and multinational joint research efforts. These efforts, though most are generic in nature and not site specific, have resulted in providing invaluable data and answers. They have validated models and verified test data, and demonstrated various investigatory techniques and methods, overall providing general support of the concept of geologic disposal of high-level waste.

However, as several States move closer to the stage of identifying sites for deep geologic repositories for disposal, their safety assessment activities are tending to move from generic studies towards site-specific assessments using the data obtained from investigations at the identified sites. Experience performing site-specific safety assessments of actual repositories in rock formations has already been obtained at the L/ILW repositories in Sweden, Germany, and Finland and also at the repository intended for alpha-bearing waste in the USA at the Waste Isolation Pilot Plant.

The safety criteria or goals for radioactive waste repositories which have been adopted in many countries are mainly based on limiting radiation dose and/or risk to members of the public potentially receiving the highest radiation exposure. In several countries there are moves towards improving criteria so that they match more appropriately the needs of safety assessors and become more credible as safety targets.

The main issue is that at time periods far into the future, which are of interest in relation to the safety assessment of repositories, the concept of dose prediction to hypothetical groups of humans has less and less meaning, as uncertainties about them and the environment increase. In some countries, a time cut-off for assessments at 10 000 years has been proposed. This time period is being considered since after 10 000 years the risks associated with radioactive wastes become comparable to risks associated with waste generated from conventional energy sources currently being used. However, it can be seen from the results of some safety assessments that the peak in radiological impact occurs after this time. Therefore some national regulations require assessments of safety to be made until at least that peak has occurred.

Nature's own waste repository

A period of 10 000 years may seem like an eternity in terms of human civilization, but for the earth, it's only a fraction of the evolution it has gone through so far. Geologic disposal (or isolation) of radioactive materials is not a man-made concept. Nature has already proven that geologic isolation is possible through several natural examples (referred to as natural analogues).

For example, the most significant case occurred almost 2 billion years ago in what is now Gabon in West Africa, where a spontaneous nuclear reaction occurred within a rich vein of uranium ore — a natural nuclear reactor. This natural reactor continued for about 500 000 years (before eventually turning itself off), and produced all the important radionuclides present in high-level waste. The incredible feature of this event is that these radionuclides remained around the site and eventually decayed into non-radioac-

At a site in Gabon, a spontaneous nuclear reaction producing radioactive waste occurred hundreds of thousands of years ago.

tive elements. The study of these natural analogues is an important component in the assessment of geologic repositories and is the subject of several international research projects, including the Alligator River and Cigar Lake Projects.

Facts and perceptions

In years ahead, radioactive waste management and disposal will, and should, receive much attention from governments and the public. Like anything else, a certain amount of awareness is healthy and necessary to keep programmes in check, on track, and in focus. However, this attention also can be destructive when taken to extremes. It can impede and even stop scientific progress.

As we move toward the 21st century, humanity cannot afford to eliminate the peaceful uses of the atom. It should be recognized that radioactive waste is a natural byproduct of these uses and can be dealt with in a safe, effective, and economical way.

In the sometimes heated debates and anxieties over radioactive waste management and disposal, the following facts should be known and considered:

- Radioactive waste is tangible and can be contained.
- Radioactivity can be precisely measured.
- Toxicity of radioactive materials decreases with time.
- Total amounts of radioactive wastes are relatively small compared to other types of wastes from industries.
- High-level waste is an extremely small part of the total amount of radioactive waste.
- Safe, proven interim storage for all wastes exists.
- Final waste disposal facilities exist for short-lived and other low-level wastes.
- Safe methods for high-level waste disposal are known.
- Extensive international networks exist for the exchange of information.
- There is international consensus on the safety assessment of repositories.
- Only a minor part of nuclear electricity costs are for waste management and decommissioning of nuclear facilities.

In assisting countries with their activities, the IAEA will continue to provide a range of services to help further strengthen the global foundation for safe and reliable radioactive waste management. ❐