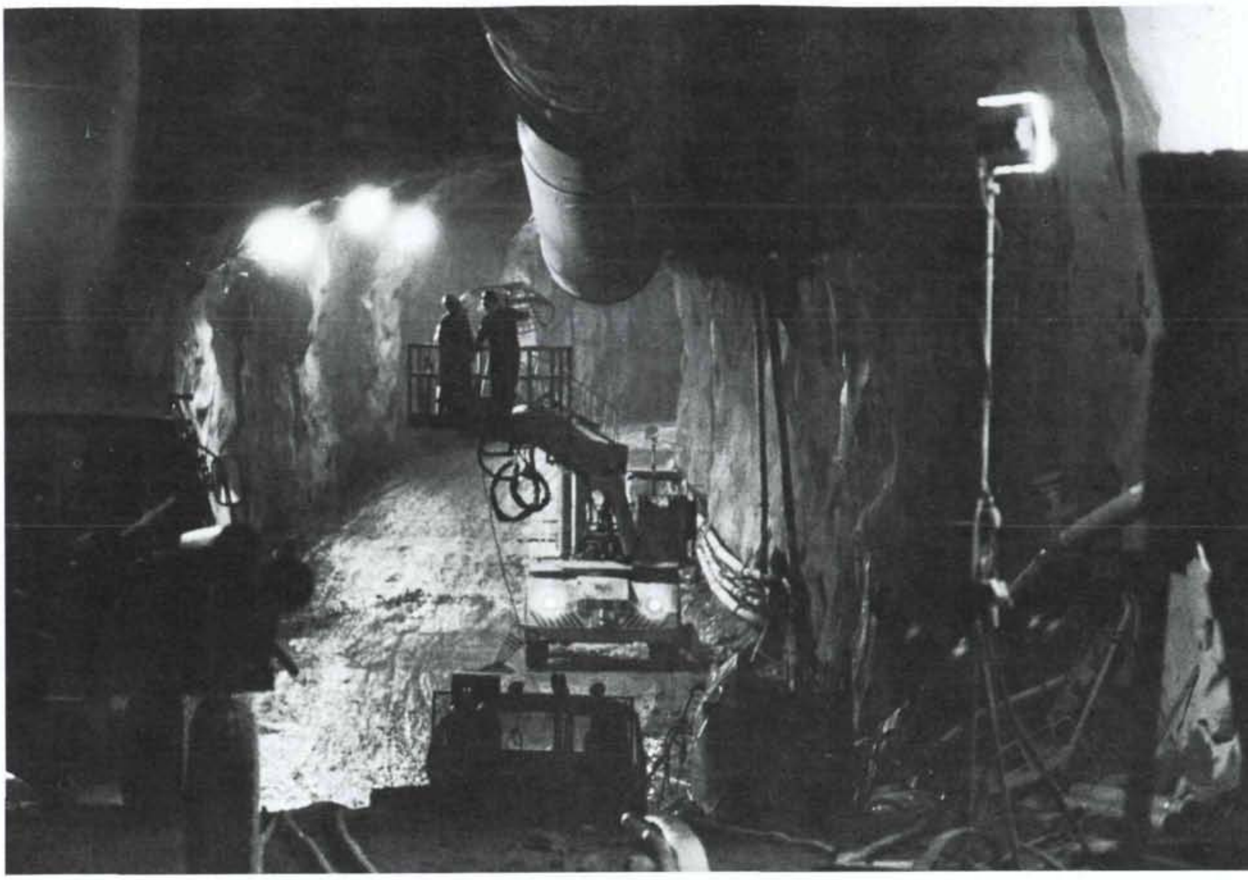
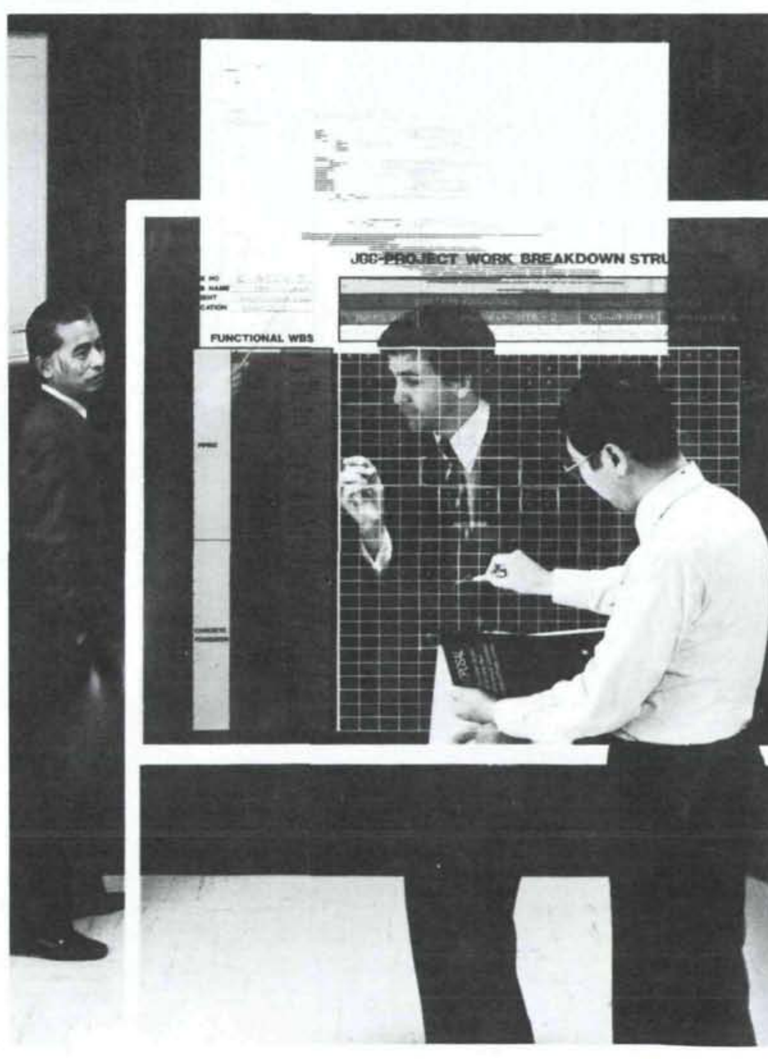
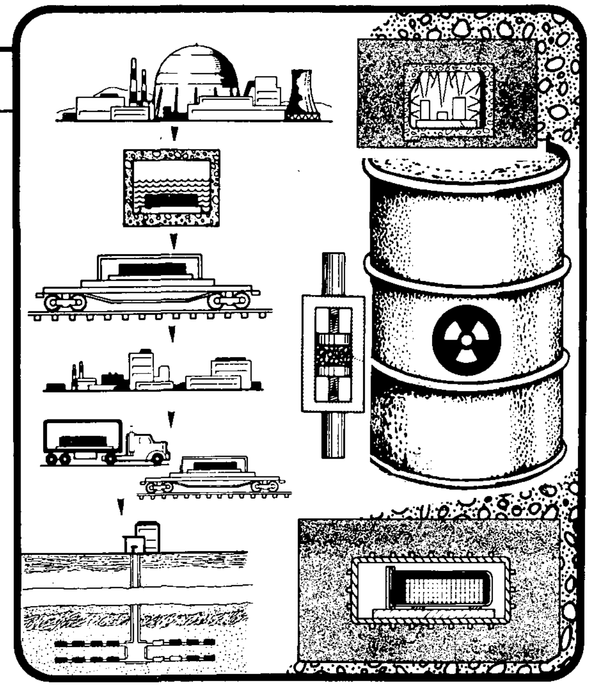




At many levels, project teams in various countries are working on programmes for the safe and effective storage and disposal of radioactive wastes. Shown here are a management team in Japan and excavation workers in Sweden's planned repository at Forsmark. (Credit: JGC, SKB)



World status of radioactive waste management

Though much progress has been registered, some questions need to be resolved

by Donald E. Saire

With a history of over 40 years of development, the use of the atom for the benefit of mankind can now be classified as a maturing technology. However, as is the case with other technologies, the benefits that result from the use of nuclear energy are not without problems. Radioactive wastes are generated not only from the operation of nuclear power plants and other fuel cycle activities but also arise from medical, industrial, and research applications of radioisotopes and from operations which would not be classified as nuclear-related activities (i.e., phosphate processing and gold mining).

Thus, almost every one of the IAEA's 112 Member States generates some volumes of radioactive wastes that must be collected, processed, and disposed of safely. These operations should be performed in a manner that considers the safety and protection of present and future generations from possible harmful exposure to ionizing radiation.

While the actual volumes of wastes generated from nuclear energy are small compared to other technologies or industries, (e.g., coal-burning power stations), the major concern is the long periods of time that radioactive wastes can still pose a threat to man and his environment. For this reason the field is now receiving the attention necessary to ensure that associated problems are resolved in a timely manner. Indeed, if nuclear energy, and more specifically nuclear power, is to continue to grow and reach the full potential of its contribution to mankind, the waste management problem must be resolved to the satisfaction of both the scientific community and general public.

This article briefly surveys activities that are under way in Agency Member States to ensure that radioactive wastes are safely managed, and it discusses some outstanding issues related to the subject.*

Activities and practices of Member States

In the early years of implementation of nuclear technology, radioactive wastes were often considered as a rather peripheral issue with little attention given to proper treatment and conditioning of wastes. In comparison to other fuel cycle activities, relatively little research and development (R&D) was directed to waste management, as rather simple interim measures were practiced. Low- and intermediate-level wastes (LILW) were usually disposed of in shallow land burial, with little treatment or conditioning of the wastes, while some countries used the sea disposal route. Alpha-bearing wastes (also called transuranic, plutonium-contaminated material, or simply "alpha wastes") were normally stored to await processing at some future date. High-level liquid wastes were collected in large carbon or stainless steel tanks at or just below ground level.

Increased concern about radiological and environmental issues in the early 1970s led many countries

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* A more comprehensive general review of the field is featured in the IAEA booklet *Radioactive Waste Management: A Status Report* (August 1985), currently available in English only.

to place greater emphasis on the management of radioactive wastes and significant R&D efforts were initiated. At first, these efforts concentrated on the treatment and disposal of high-level wastes, since this waste stream contained a significant fraction of the activity inventory. However, the large volumes of low-level liquid and solid wastes being generated by nuclear power plants and non-fuel cycle facilities also resulted in a rapid expansion of research activities on these wastes.

Reviewing the current status of activities associated with the treatment (volume reduction), conditioning (waste immobilization) and disposal of LILW clearly exhibits the emphasis now being placed in this area. (See the accompanying table for activities in progress or proposed in several Member States.) The major emphasis has been placed on the treatment of low-level wastes to reduce their volumes, not only to permit easy handling and further processing but also to reduce space requirements for final disposal.

For low-level liquid wastes, the classical engineering processes of evaporation, ion exchange, and chemical precipitation have been adapted from other industries and modified to meet the requirements of radioactive waste treatment systems. These processes now are in operation in many countries and represent simple technology, capable of reducing waste volumes by factors ranging from 10 to 100 of the original volumes in a safe and effective manner.

Current efforts for the treatment of solid LILW also are shown in the accompanying table. Either compaction or incineration, or in some instances a combination of both technologies, is now being utilized, depending on the character of the solid wastes, the volumes generated, and the final disposal method selected by the country.

Volume reduction factors for compaction usually range from 5 to 10 of the original volume. Incineration of solid wastes offers much larger volume reductions (greater than 20) but is usually limited to countries that generate large quantities of low-level combustible wastes. The immobilization of LILW is practiced by most countries operating large nuclear research centres and/or nuclear power stations. Immobilization of the liquid and solid waste usually follows some volume reduction treatment. The well-established technology of cementation has been used for many years now but other immobilization matrices, such as bitumen and polymers, have been introduced into several countries and are under active investigation.

All immobilization processes for LILW provide the necessary solid-waste matrix to prevent early release of radionuclides to the environment when the resulting solidified waste products are disposed of in engineered storage facilities. Disposal of treated/immobilized LILW depends on the availability of land masses, geological formations, and the hydrology of a country.

In the initial years of nuclear energy, sea dumping was considered a suitable disposal route with acceptable low radiological consequences. Public opinion and poor management practices, however, have closed this option for the immediate future. Most Agency Member States now dispose of LILW in surface or near-surface facilities constructed with suitable engineered barriers. Geological disposal in old mines and deep well injection (hydraulically fractured rock) also are practiced in a few countries (for example, the German Democratic Republic, the Federal Republic of Germany, and the United States, among others).

National activities: Low- and intermediate-level (short-lived) wastes

	Volume reduction		Immobilization		Disposal practice	
	Liquid	Solid	Cement	Others	Surface	Sub-surface
Argentina		■		■	■	
Austria	■	■	■			
Belgium	■	■	■	■	●	
Bulgaria	■			■	■	
Canada	■	■		■	■	■
China	■		■	■		
Czechoslovakia	■	■		■	■	
Egypt		■	■			■
Finland	■	■	■	■	■	●
France	■	■	■	■	■	■
German Dem.Rep.	■	■		■		■
Germany, Fed.Rep. of	■	■	■			■
Hungary	■		■			■
India	■	■	■	■	■	■
Italy	■	■	■	■	■	■
Japan	■	■	■	■	■	●
Korea, Rep.of	■	■	■	■		■
Netherlands	■	■	■			
Poland	■	■		■	■	
Romania	■	■	■		■	
South Africa			■			■
Spain		■	■			■
Sweden			■			■
Switzerland		■	■			●
United Kingdom	■	■	■	■		■
United States	■	■	■	■		■
USSR	■	■		■	■	■
Yugoslavia	■		■		■	

■ = Practice in use
● = Practice is proposed

Source: Abstracted from IAEA booklet *Radioactive Waste Management: A Status Report* (August 1985).

Strategies for high-level and alpha wastes

National strategies for the management of high-level wastes usually are dictated by a nation's fuel cycle decision on whether to reprocess or store spent fuel. This to some extent also is the case with alpha-bearing wastes, although quantities of these wastes can be generated from research activities. (See the table, page 7, for a summary of the current status for the management of alpha-bearing and high-level wastes in several Member States.)

National activities: Alpha-bearing and high-level wastes

	Alpha-bearing		HLW	Disposal of Alpha/HLW	
	Volume reduction	Immobilization	Immobilization	Interim	Geological
Argentina			R&D		
Austria			CPP		
Belgium	■	■	R&D		●
Canada			R&D		
China			R&D		
France	■	■	HF(o)		●
Germany, Fed. Rep. of	■	■	HF(o)		●
India	●		HF(o)		●
Italy	●	■	CPP		●
Japan	●		HF(c)		●
UK	●	■	HF(c)		●
USA	■	●	HF(c)		●
USSR	■	■	CPP		●

Legend: ■ = current activity
● = proposed activity
R&D = research and development
CPP = cold pilot plant
HF(o) = operation of hot facility
HF(c) = construction of hot facility

Source: Abstracted from IAEA booklet *Radioactive Waste Management: A Status Report* (August 1985).

Technologies for the treatment of alpha-bearing waste are under development and have been implemented in many countries. Volume reduction techniques in use for several years include acid digestion, incineration, and pyrolysis of the wastes. Of these technologies, incineration of alpha-bearing combustible wastes has received considerable attention and new incinerator plants, especially designed to handle alpha-bearing wastes, are now in operation in the United States and other countries.

Immobilization of alpha-bearing wastes has to a large extent been performed by embedding the wastes in cement or bitumen. Disposal of alpha-bearing wastes is dependent on the activity levels of the wastes and the national regulatory standards concerning disposal. Most Member States follow the practice of controlled storage of treated or conditioned alpha-bearing wastes for an interim period of time in engineered disposal facilities at or near the surface. In the future, it is expected that alpha-bearing wastes that exceed the limits for surface burial will be disposed of in deep geological repositories similar to the Waste Isolation Pilot Plant (WIPP) now under construction in the USA.

The high-level waste management programme in countries pursuing the fuel reprocessing option is based on immobilization of high-level waste forms into a monolithic solid form. A large amount of investigation of alternative high-level waste forms was undertaken during the late 1970s and early 1980s considering such waste matrices as denitrated calcines, glasses, and crystalline ceramics.

During the past few years, there has been a growing consensus in many countries that presently glass appears to offer the best compromise between desirable waste form properties, ease of fabrication, and a long history of material experience. Research and development on crystalline waste glass forms is continuing in many countries, with borosilicate glass now emerging as the internationally recognized reference high-level waste form.

Regarding the extent of the technology base for immobilization of high-level waste in borosilicate glasses or other media, several Member States are engaged in activities ranging from modest cold R&D operations to actual full-scale high-level waste vitrification facilities. (See table on page 8.)

Conditioned spent fuel

While most countries involved in the nuclear fuel cycle are planning to reprocess spent fuel, several nations are pursuing the once-through fuel cycle and examining conditioned spent fuel as a final high-level waste form. This concept is under study in at least six Member States of the Agency – Canada, Finland, Spain, Sweden, Switzerland, and the United States.

In recognition of this option, the Agency recently has expanded the scope of a newly established co-ordinated research programme on the evaluation of solidified high-level waste forms and engineered barriers under repository conditions to include spent fuel. The option of conditioned spent fuel as the final high-level waste form will no doubt receive more attention as the economics for fuel recycle become increasingly marginal and Member States balance the advantages and disadvantages of the additional technical complexity and handling steps necessary for the conversion of high-level waste to a solidified waste matrix.

Major high-level waste and spent-fuel disposal facilities

Current national programmes for several Member States of the Agency to build and operate high-level waste (HLW) and/or spent-fuel disposal facilities are summarized below. Most planned facilities relate to the vitrification of HLW and storage of the product waste forms.

Country	Facility	Status*
Argentina	• Repository for HLW glass	1984**
Belgium	• Repository for alpha wastes	mid-1990s
	• AVB-vitrification plant for existing Eurochemic liquid HLW	Project approval uncertain
Canada	• Repository for spent fuel	2010 or later
Finland	• Repository for HLW or spent fuel	2020
France	• AVH vitrification plants (La Hague)	1987/89
Germany, Fed.Rep.of	• AFR storage hall for spent fuel (Gorleben)	1984
	• Waste repository (Gorleben)	1995
India	• WIP, waste immobilization plant at Tarapur for HLW, other reprocessing wastes	1983
Japan	• HLW vitrification plant at Tokai works	1991
	• HLW glass storage at Tokai	1992
	• Commercial HLW vitrification plant	1997
	• Repository for HLW glass	2020
Spain	• Repository for spent fuel	2005/10
Sweden	• CLAB AFR storage facility for spent fuel and HLW glass	1985
	• Repository for HLW/spent fuel	2020
Switzerland	• AFR storage facility for spent fuel, HLW glass, other reprocessing wastes	1992
	• Geological repository for HLW or spent fuels	after 2020
United Kingdom	• Windscale vitrification plant for HLW at Sellafield	1988
United States	• Vitrification plant for West Valley HLW	1988
	• Vitrification plant for Savannah River HLW	1989
	• First repository for HLW or spent fuel	1998
	• WIPP (demonstration repository for defence alpha wastes)	1989

* Status reflects start-up, unless otherwise indicated.
** Complete site characterization.

Although high-level waste products from vitrification plants and conditioned spent fuel appear destined to be stored permanently in geological repositories, few national sites currently are being developed. Planning and development activities have been initiated, however. Since high-level waste products and spent fuel can be safely stored in facilities above ground for many decades, it is unlikely that permanent repository facilities for these wastes need to be in operation before the first part of the 21st century.

Issues and open questions

In discussing the status of radioactive waste management, one cannot leave the subject without at least briefly covering some issues and open questions that surround this field. On many occasions the Agency and other national and international bodies have stated that there are no technology barriers that prevent mankind from safely managing nuclear wastes to protect this and subsequent generations.

In fact, one main conclusion of the International Conference on Radioactive Waste Management, which was sponsored by the Agency in May 1983, was that "adequate technology exists and proper geological formations deep underground can be chosen" for the "safe long isolation" of radioactive waste.* While most individuals known in this field will agree with this statement, there are still some rather sensitive areas requiring understanding and prudent action among responsible national and international bodies before we can proceed with the final stages of the work. Some of these issues, described below, require actions and types of activities that are not the usual traits of the technologist.

* From remarks delivered by Hans Blix, Director General of the IAEA, at the International Conference on Radioactive Waste Management in Seattle, Washington from 16 to 20 May 1983. For a report on the conference, see the *IAEA Bulletin*, Vol. 25, No.4 (December 1983).

Government policies and public opinion

Waste management, despite being a field which generates a high degree of discussion and interest from the scientific community, now is the centre of attraction of many State and local bodies. While technology has been developed and, to the most extent demonstrated, to show that radioactive waste can be safely managed now and in the future, plans for disposal of wastes, in many countries, are now being determined not by technical factors but by the attitudes of the general public and local governments. Since these attitudes are formulated from actions and practices of the nuclear industry, there is a mandate for the international nuclear community to clearly and effectively plan all waste management activities on sound technological bases that carefully consider the safety of man and the environment before such actions are implemented.

Interaction with public interest groups can only be favourable if technical responsibility and open access to information are the main features of a public acceptance programme. It is notable that in Sweden the programme of the Swedish Nuclear Safety Project (KBS) has succeeded in satisfying a "stipulation law" where failure to make progress with waste disposal plans could have prevented the loading of fuel into newly constructed reactors. Sweden's very open approach to public information access and a sound technical concept should be looked at as a guide for achieving public acceptance to waste treatment and disposal plans.

International co-operation

While it is recognized that to a certain extent waste management activities cannot be isolated at the national boundaries of countries, little progress seems to be made on issues which require an international forum for discussion and decision-making. While the IAEA and other international organizations involved in the peaceful use of the atom act as catalysts on certain global waste management issues, no progress had been made on the question of international waste diposal facilities.

One particular concern is defining the responsibility that nations and the international community have to countries with small nuclear programmes and/or with limited or no suitable land areas for the disposal of wastes generated from the operation of nuclear power plants. While the incentive to sell nuclear power stations to countries offers economic reward to vender nations, should it not also include the liability of providing safe, final disposal of wastes generated from these power plants if the purchaser does not possess the technology or suitable geological formations for isolating these wastes? This issue will have to be addressed by the international community in the very near future, as several nations operating or planning nuclear power plants will eventually be faced with waste disposal problems that may not be feasible or practicable to solve within national boundaries.

Geological disposal of waste products

The technology for the deep geological disposal of spent fuel and/or solidified high-level waste packages is advancing steadily, but there still are areas which need further clarification: What constitutes an adequate demonstration of future safety and how can a balance be struck between minimizing the radiological doses to present and future generations? Also, at what point is an effective balance made that encompasses the whole waste disposal system – that is, the waste matrix, container, engineered barriers, backfill material, and host rock?

Scientific and social reasoning must eventually support the concept that it is not feasible or even desirable to ensure that each component of the multi-barrier waste containment system be optimized to the "n^{th}" degree to ensure acceptable radiological risks to existing and future generations. Rather, agreement has to be reached that acceptable barriers for each component of the system will integrate into a total "fail-safe system".

In concluding, it is certainly worthy to note the degree of progress that has evolved in the management of radioactive wastes. Technologies and practices by nations using the atom are safe and sensible to the need to protect mankind and his environment from radiological risks. Technologies to perform the required waste processing and isolation are available. Can we afford not to combine forces and resolve, once and for all, the remaining issues surrounding radioactive waste management that slow our progress and prevent mankind from reaping the full benefit of the atom?