Radioactive waste disposal: Global experience and challenges

With extensive experience in disposal of low- and intermediate-level radioactive wastes, countries are addressing some new challenges

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Since the world's first disposal of radioactive waste in Oak Ridge, Tennessee, in 1944, considerable experience has been acquired in the field. The first disposal site — intended for "actively contaminated broken glassware or materials not sufficiently clean to be used in other work" — was a simple trench filled with unconditioned waste located on the Oak Ridge site. Similar approaches were adopted by other nuclear facilities and waste generators in the United States and other countries during the early phases of nuclear power's development.

Today, the world's disposal sites for low- and intermediate-level radioactive wastes (LILW) range from near-surface facilities to engineered geological repositories. More than one hundred LILW disposal facilities are, or have been, operating, and more than 42 repositories are under some stage of development in the IAEA's Member States. *(See the table on pages 38 and 39.)*

Accompanying the progress, a number of issues and challenges have arisen in countries pursuing radioactive waste disposal options. At the global level, the IAEA has been working to assist them in these efforts by promoting the transfer of technologies, particularly to developing countries. The work entails the collection, summary, and dissemination of updated technical information and support for co-ordinated research programmes on specific technical aspects. Within that context, this article presents an overview of international experience in land-based LILW disposal systems, and addresses the emerging issues and challenges now facing countries in this field.

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Practices and trends

Site selection. Siting a radioactive waste disposal facility refers to the process of selecting a suitable location that must take into account technical and other considerations. Technical factors cover a long list: geology, hydrogeology, geochemistry, tectonics and seismicity, surface processes, meteorology, human-induced events, transportation of waste, land use, population distribution, and environmental protection. Another key factor today is public acceptance, particularly in industrialized countries where a locality's "not-in-my-backyard" attitude can hinder the siting of all types of industrial waste facilities, not just radioactive waste sites. This has caused planners to focus greater attention on societal factors during early phases of the siting process. In some cases, repositories are being co-located at sites where nuclear facilities already exist; for example, Drigg (UK), Centre de la Manche (France), Rokkasho (Japan), and Olkiluoto (Finland). Some countries also have talked about the concept of siting a regional-multinational repository (discussed in more detail later). However, political factors and public concerns have kept any regional repositories from being developed in the world.

Currently in countries around the world, at least 17 sites have been selected for new LILW repositories, some of which already are licensed or under construction, while more than 25 sites are being investigated in 17 countries. They include China, which is planning to develop four LILW repositories, and has selected two sites for its northwest and southern regions. The northwest disposal site is located in an arid and sparsely populated area of the Gobi Desert. In the United States, no new commercial repository for low-level wastes has been constructed since the passage of the Low Level Radioactive Waste Policy Act of 1980. In eight US states, the site selection process is in some stage of progress. Four sites already have been selected by Nebraska (Central Interstate Compact), North Carolina (Southeast Compact), California (Southwest Compact) and Texas (pending the Texas Compact), and are now in the licensing process.

In addressing public acceptance issues, countries are taking several kinds of steps. In Australia, a comprehensive public consultation process characterizes the process of selecting the site of an engineered LILW repository. In Canada, where community opposition delayed the siting of a disposal facility for waste from radium and uranium refining activities, the Government halted the first site selection process and established a co-operative five-phase programme implemented by an independent siting task force. The task force works closely with municipal councils of the participating communities and with community liaison groups set up as information conduits with the general public. In Hungary, after two siting attempts stalled, a national siting project for LILW disposal was initiated by the Hungarian Atomic Energy Commission in 1992. Following a volunteer approach, the AEC found communities that volunteered to host sites, and in those that did, six sites have been selected. The communities now will be involved in detailed site investigations. In the United States, similar approaches also have been initiated. For instance, in Connecticut, where public resistance initially was met, the process was adapted to allow for greater public involvement on two aspects — "choice and control" — that may significantly influence the way the siting process is perceived and received.

Design factors. The type of repositories ultimately selected depend upon each country's geological conditions, specific disposal requirements, and regulatory approaches. All of these factors are tied to the facility's design. In general, the design aims to limit the release of contaminants or radionuclides to the biosphere; minimize exposure of workers and the public; and minimize maintenance during the post-closure phase. The aims can be achieved through technical components such as the waste package, engineered structures, the site itself, or a combination of these.

Some noticeable trends in design are related to technological advances in the field of waste disposal and public concerns over safety. One general tendency is that more reliance is being placed on a system of multiple engineered barriers to contain the waste. Such a system includes concrete vaults, backfilling materials, chemical barriers, and measures for gas venting, drainage, and buffer zones.

Worldwide, several different types of LILW facilities have been designed. About 62% of LILW repositories are engineered near-surface facilities within about 10 meters of the earth's surface, 18% are more simplifed near-surface facilities, 7% are mined cavities, and 4% are geological repositories. The type of facility ultimately selected and designed depends on the characteristics of the waste itself, as well as the site, and on national strategies and social and economic factors. Following are brief overviews of the different designs:

Simple near-surface facilities. Examples of these types of facilities include Barnwell (USA), and Vaalputs (South Africa), both of which benefit from the low permeable clay layer and/or low precipitation rate at the site. At Barnwell, the disposal system consists of trenches with a slightly sloped floor covered with a layer of sand to facilitate collection of infiltrating water in a trench drain. The trench drain ends in a sump which is monitored. Waste, packaged in boxes, drums and casks, is stacked in the trenches. Higher activity wastes are conditioned with concrete, bitumen, or other low leachability materials or placed in high integrity containers for structural stability. The space between the waste containers is filled with dry soil, and the trench is then covered with clay and soil. In Vaalputs, long and wide trenches, nearly eight meters deep, are covered by several layers of compacted clay and indigenous sand and vegetation.

Engineered near-surface disposal facilities. Examples here include the Drigg (UK) facility, where a simple trench concept was phased out in favour of engineered vaults. It is designed to accept LLW waste packages in containers of highly compacted waste in steel overpacks that forklifts then place into concrete vaults. The vaults, set on or below ground level, consist of a concrete base and walls with an underlying drainage layer. Any drainage from within or below the vault can be independently monitored and routed to an on-site water management system before discharge via a marine pipeline.

Concrete vaults in a box design are being used at sites including the Centre de la Manche and l'Aube (France), El Cabril (Spain), Trombay (India), and Rokkasho (Japan). Each one has unique design features. At la Manche, drums containing more active short-lived LILW are built into concrete walled monoliths at the base, with drums of lower activity stacked on top and then covered. The second French repository, l'Aube, takes advantage of the experience. There, all waste is isolated within reinforced concrete vaults (30 meters wide, 30 meters long, 8.5 meters high, with 30-centimeter thick walls). Vaults are built above the highest level of the groundwater table, and have additional design features to guard against rainwater infiltration. Also developed was a waste package handling system that workers operate remotely, which reduces their exposure to radiation. Based on earlier experience, a highly automated record management system was created.

In Spain, El Cabril follows a similar disposal concept, and incorporates the potential retrievability of waste packages; it also has waste conditioning and characterization facilities. In India, where six LILW repositories are operating, the design features reinforced concrete trenches and tile holes for different types of waste. At Trombay, the reinforced concrete trenches are waterproofed and covered with reinforced concrete; additional water repellants are used to prevent any ingress of monsoon water. Circular tile holes some four meters deep are designed to accommodate waste with activity higher than permissible for reinforced concrete trenches and for storage/disposal of alpha contaminated waste.

In countries of the former Soviet Union, LILW disposal facilities typically were built in the 1960s and 1970s and have been used for waste containing various radionuclides. Similar types of repositories were built in Eastern European countries. The standard design called for them to be located at least four meters above the water table. At the Sergiev Posad repository (Russia), concrete vaults were built just below ground surface. They are made of double-layered concrete walls containing bitumen layers. Waste packages are placed in individual compartments that are filled in with mortar made of cement and low-level liquid waste. When a compartment is full, the waste is covered by a concrete layer as well as a re-enforced concrete plate, two layers of bitumen, and a clay soil cap.

In Japan, at Rokkasho-mura, concrete pits are used between which a drainage system is installed as an engineered barrier in view of the fact that the repository is located under the groundwater table. One pit can accommodate approximately 5000 drums. Once full, the disposal pits will be backfilled and covered with at least four meters of soil.

In Canada, waste disposal engineers have designed what is called the "intrusion resistant underground structure", or IRUS. Its features include a concrete module with a thick concrete cap and permeable bottom that will be built above the water table in a sand formation. The permeable floor is designed to minimize the contact of water with the waste. Since the waste will contain small concentrations of very long-lived radionuclides, engineers have planned for the eventual infiltration of water as the concrete deteriorates over the long term: any water is channeled to readily drain through the floor, which is formed of two mixed layers of sand, clay, and natural zeolite. The adsorptive properties of the layers will limit the release of radionuclides with the draining water.

Mined cavities. This concept is followed in the Czech Republic, Sweden, Finland, and Norway, for example. In the Czech Republic, part of Richard II mine cavern, 70 to 80 meters underground, is used as a repository for institutional radioactive waste (mostly short-lived). Currently, the mine is dry and its geological environment is marly limestone and marlstone. In Sweden, the Swedish Final Repository (SFR) is built in crystalline rock about 60 meters under the sea bottom with access from land. The layout of the rock chambers have been adapted to the different types of short-lived LILW, their radioactivity content, composition, and handling requirements. Silo-shaped caverns 50 meters high with concrete walls, a bentonite clay buffer, and gas venting system house the waste packages containing the highest levels of activity. In Finland, Olkiluoto is similar to the SFR but it has only two silos — one for low-level wastes and the other for heatgenerating intermediate-level wastes — constructed 60 to 100 meters underground. Crushed and ground host rock is used as backfill, and major water-bearing fracture zones will be sealed with concrete plugs.

Geological repositories. The Morsleben and Konrad (Germany) sites, as well as the planned NIREX repository (UK), are examples of geological repositories for LILW. Morsleben is located in a very dry and stable salt mine roughly 500 meters underground, and has a capacity of 40,000 cubic meters of waste. ILW are disposed of in a large cavity which is then backfilled in layers for shielding; LLW is stacked in excavated chambers. The Konrad site is an exceptionally dry former iron mine which is easy to mine, stable, confined by other layers, and covered by about 400 meters of thick clay. According to the safety assessment, the time for water to travel from the repository to the surface would be 380,000 years. Horizontal repository tunnels are to be built at a depth of about 800 meters for disposal of non-heat generating wastes, while two shafts and tunnels will be used for transportation.

Licensing. Because of different legal and regulatory structures and requirements, the licensing process differs among countries. For instance, in Germany a single licensing process covers construction, operation, and closure of a repository, whereas several licensing steps are required in other countries. In general, the license application is based on site-specific repository design and safety assessments which must demonstrate compliance of the proposed facility with regulatory requirements. Licensing typically involves complex legal and political procedures, intensive technical reviews by the regulatory body, and interaction with the public.

In Switzerland, the site of Wellenberg in Canton Nidwalden was announced in June 1993 as a suitable potential site for LILW disposal after extended investigations. The Swiss licensing procedure includes federal, cantonal, and community licenses for the construction and later for the operation of the repository. In addition, a special mining concession must be granted by the Canton. The general license was submitted to the Swiss Federal Government in June 1994, whose decision is subject to ratification by the Federal Parliament. In the meantime, the siting community of Wolfensehiessen and the community assembly voted in favour of the project in 1994. However, the cantonal vote in June 1995 regarding the mining concession was slightly negative.

In Germany, the Konrad mine in Lower Saxony was investigated from 1976 to 1982 to determine its suitability as a radioactive waste repository. When the investigations were completed, application was made for a license to begin repository construction. While all hurdles have been passed at the federal level, the regional government has not rendered its decision on the license application. In the United States, four states (California, Nebraska, North Carolina, Texas) submitted license applications in late 1989, July 1990, December 1993, and March 1992, respectively. Up to now only California has obtained a license, issued by the California Department of Health Services (DHS) on 16 September 1993. However, the license was conditioned on DHS ownership of the land. On 1 June 1994, the Superior Court of the State of California ordered DHS to reconsider its approval of the license. DHS is appealing the court's order. In Nebraska, US Ecology, which has responsibility for siting, submitted the eighth and final revision of the Safety Analysis Report plus various other documents relating to the license application on 15 June 1995. In North Carolina, due to political reasons, the application will not be approved before February 2000 by the state's Division of Radiation Protection in the Department of Environment, Health and Natural Resources.

Closure. Once a disposal facility is full, or disposal operations are stopped for other reasons, the process known as "closure" and "post-closure" begins. The closure process include steps to secure the facility, such as covering or sealing the disposal areas, compiling documents, and performing safety assessments. In many countries, several hundreds of years are foreseen for post-closure institutional control. This may include access control, maintenance, site monitoring, recordkeeping and corrective actions, if required.

In France, the Centre de la Manche received its last waste package in June 1994 and steps now are being taken in preparation for closure. The facility operator, the French National Radioactive Waste Management Agency (ANDRA), has applied for a license concerning the institutional control phase. Once the licence is granted, the site will continue to be under ANDRA responsibility. The license is expected to be granted in 1997, following a second public hearing that will provide guidance on institutional control activities including active and passive surveillance.

Emerging issues and challenges

A number of issues have emerged that are drawing close attention at the national and global levels. They include those concerning:

Naturally occurring radioactive materials (NORM). The earth's environment includes naturally occurring radionuclides, including potassium-40 and carbon-14, and radioactive heavy elements originating from the uranium and thorium decay series. They can be contained in residues, or wastes, resulting from any activities that involve removing natural materials from the earth or processing those materials (e.g. mining or oil and gas production). Also coal combustion results in concentration of radionuclides in the ash as well as significant airborne release of radioactivity. The radiological hazard due to NORM in waste products is mainly from radium and its progeny. Associated radiation doses may not be insignificant and indeed will often be higher than radiological standards set for the control of radiation from practices involving the use and application of radioactive materials.

The concerns have prompted regulators to consider the potential hazards associated with disposal of NORM wastes. In some countries, some of these wastes are now managed like radioactive waste although the level of control varies widely. A recent survey has shown that radionuclide concentrations in oil/gas processing pipelines can approach levels above which it would be deemed unacceptable for near-surface disposal of radioactive waste. In some countries, some byproducts of oil/gas production and processing are already managed as low-level radioactive waste, while in other countries it remains uncontrolled.

Very low-level waste (VLLW). This type of waste sometimes is generated in large volumes but carries low potential hazards. It creates a problem because it is neither practical to dispose of it in LILW repositories nor acceptable to dispose of it as industrial waste. Presently, there is no internationally agreed definition of VLLW, and the issue's resolution depends upon the development of regulatory criteria, among other factors.

In Sweden, several earthen mound facilities are in operation at each nuclear power plant site to dispose of VLLW. Such disposal can only be exercised for the waste requiring less than 100 years of radiological control. In France a large portion of VLLW is sent to the L'Aube repository while the remaining portion is kept at the sites. All told, French industry officials estimate the total amount of VLLW to be about 15 million metric tons, and efforts have intensified to find a more satisfactory solution to its disposal. A recent study by an industrial working group considered four types of disposal facilities for VLLW, three in tumulus structures and one underground. These designs are under review by the licensing authority. In Japan, the Japan Atomic Energy Research Institute (JAERI) has launched a programme to demonstrate the safety of near-surface disposal for VLLW. The type of waste for disposal in the demonstration project is mainly concrete chunks of reactor shields and contaminated structures from the country's Demonstration Power Reactor containing radionuclides several orders lower than the legal limits. Having obtained approval for building the test facility, a pit has been excavated at the reactor site, which accommodated 1700 tons of the waste from November 1995 to March 1996. The disposal pit has been covered by a thick landfill with grass on top and the site will be controlled for about 30 years.

Spent sealed radiation sources (SRS). More than half a million sealed radiation sources are widely used in medicine, research, agriculture, and other fields. Once used, or spent, they require careful management before their safe disposal. Experience has been acquired for all steps in the management of spent SRS, except for the disposal of long-lived sources. However, not all countries have the resources to implement existing methods.

Provided a near-surface facility is properly sited, constructed and operated, it may safely be used for the disposal of most spent SRS, with the exception of americium-241 and radium-226 and the large sources used in teletherapy or radiation facilities. The acceptability of waste at a given repository is subject to criteria which include a concentration limit for the different radionuclides or groups of radionuclides in a waste package and the total activity.

Many countries generate only small amounts of radioactive waste including spent SRS, up to a few cubic meters per year. These countries could benefit from establishing regional-multinational repositories. Other countries with operational repositories are facing different types of concerns with spent SRS. For example, in Russia, long-lived spent SRS (e.g. radium sources) are stored for future geological disposal and others are disposed of in concrete vaults or in boreholes built in shallow ground. The borehole concept, developed from the end of 1950s to the beginning of 1960s by the former USSR, involves dropping spent SRS through a spiral loading channel into a five meter deep stainless vessel situated in a concrete-lined bore-

Status of low and intermediate level waste disposal facilities in various countries in 1996

Country	Repository (date opened/closed)	Repository Concept
In the process of site selection		
Australia		ENSF
Belgium		ENSF
Brazil		ENSF
Bulgaria		ENSF
Canada (historic LLW)		-
China (East)		-
(Southwest)		-
Croatia		-
Cuba		MC
Ecuador		ENSF
Hungary		-
Indonesia		ENSF
Korea, Republic of		-
Pakistan		-
Slovenia		-
Turkey		ENSF
United Kingdom		GR
United States (Connecticut)		-
(Illinois)		ENSF
(Massachusetts)		-
(Ohio)		ENSF
(Michigan)		ENSF
(New Jersey)		-
(New York State)		ENSF
(Pensylvania)		ENSF
Site selected		
China	Guangdong Daya Bay	ENSF
Cyprus	Ari Farm	SNSF
Egypt	Inshas	ENSF
Mexico	Laguna Verde	ENSF
Peru	RASCO	ENSF
Romania	Cernavoda	ENSF
Swizerland	Wellenberg	MC
Under licensing		
Canada	Chalk River	ENSF
Germany	Konrad	GR
Norway	Himdalen	MC
Slovak Republic	Mohovce	ENSF
United States	Ward Valley, California	ENSF
	Boyd County, Nebraska	ENSF
	Wake County, North Carolina	ENSF
	Fackin Ranch, Texas	ENSF
Under construction		
China	Gobi, Gansa	ENSF
Finland	Loviisa	MC
In operation		
Argentina	Ezeiza (1970-)	ENSF
Azerbaijan	Baku (1960s-)	ENSF
Australia	Mt. Walton East (1992-)	ENSF
Belarus[1]	Ekores, Minsk reg.(1964-)	ENSF
Brazil	Abadia de Goias (1996-)	ENSF
Czech Republic	Richard II (1964-)	MC
	Bratrstvi (1974-)	MC
	Dukovany (1994-)	ENSF
Finland	Olkiluoto (1992-)	MC
France	Centre de l'Aube (1992-)	ENSF
Germany	Morsleben (1981-)	GR
Georgia	Tabilisi (1960s-)	ENSF
Hungary	RHFT Puspokszilagy (1976-)	ENSF
India	Trombay (1954-)	S/ENSF
	Tarapur (1968-)	ENSF
	Rajasthan (1972-)	ENSF
	Kalpakkam (1974-)	ENSF
	Narora (1991-)	ENSF
	Kakrapar (1993-)	ENSF
Iran	Kavir Ghom-desert (1984-)	SNSF
Israel	Negev Desert	SNSF
Japan	Rokkasho (1992-)	ENSF
Kazakstan	Almaty	ENSF
	Kurchatov (1996-)	ENSF
	Ulba (1996-)	ENSF
Kyrgyzstan	Tschuj (1965-)	ENSF
Latvia	Baldone (1961-)	ENSF
Mexico	Maquixco (1972-)	SNSF
Moldova	Kishinev (1960-)	ENSF
Pakistan	Kanupp (1971-)	SNSF
	PINSTECH (1969-)	SNSF
Poland	Rozan (1961-)	ENSF
Romania	Baita-Bihor (1985-)	GR
Russia[2]	Sergiev Posad, Moscow reg. (1961-)	ENSF
	Sosnovyi Bor, Leningrad reg.	ENSF
	Kazan, Tatarstan	ENSF
	Volgograd	ENSF
	Nijnyi Novgorod	ENSF
	Irkutsk	ENSF
	Samara	ENSF
	Novosibirsk	ENSF
	Rostov	ENSF
	Saratov	ENSF
	Ekaterinburg	ENS
	Ufa, Bashkortostan	ENSF
	Cheliabinsk	ENSF
	Habarovsk	ENSF
South Africa	Pelindaba (1969-)	SNSF
	Vaalputs (1986-)	SNSF
Spain	El Cabril (1992-)	ENSF
Sweden	SFR (1988-)	MC
	Oskarshamn NPP (1986-)	SNSF
	Studsvik (1988-)	SNSF
	Forsmark NPP(1988-)	SNSF
	Ringhals NPP (1993-)	SNSF
United Kingdom	Dounreay (1957-)	SNSF
	Drigg (1959-)	S/ENSF
Ukraine	Dnepropetrovsk center	ENSF
	L'vov center	ENSF
	Odessa center	ENSF
	Kharkov center	ENSF
	Donetsk center	ENSF
United States	RWMC, INEEL (1952-)	S/ENSF
	SWSA 6, ORNL (1973-)	S/ENSF
	Disposal Area G, LANL (1957-)	SNSF
	Barnwell, South Carolina (1971-)	SNSF
	200 East Area Burial Ground, Hanford (1940s-)	SNSF
	200 West Area Burial Ground, Hanford (1996-)	SNSF
	Richland, Washington (1965-)	SNSF
	Savanah River Plant site (1953-)	SNSF

Country	Repository (date opened/closed)	Repository Concept
Uzbekistan	Tashkent (1960s-)	ENSF
Viet Nam	Dalat (1986-)	ENSF
Operation stopped or under closure		
Armenia	Erevan	ENSF
Bulgaria	Novi Han (1964-1994)	ENSF
Estonia	Tammiku (f. Saku) (1964-1996)	ENSF
France	Centre de la Manche (1969-1994)	ENSF
Germany	Asse (1967-1978)	GR
Russian Federation[2]	Murmansk	ENSF
	Groznyi, Chechnya	ENSF
Tajikistan	Beshkek	ENSF
Ukraine	Kiev center (-1992)	ENSF
Closed		
Czech Republic	Hostim (1953-1965)	MC
Hungary	Solymar (1960-1976)[3]	ENSF
Japan	JAERI, Tokai (1995-1996)	SNSF
Mexico	La Piedrera (1983-1984)	ENSF
Norway	Kjeller (1970-1970)[4]	ENSF
Lithuania	Maishiogala (1970s-1989)	ENSF
United States	Beatty, Nevada (1962-1992)	ENSF
	Maxey Flats, Kentucky (1963-1978)	SNSF
	ORNL SWSA 1 (1944-1944)[3]	SNSF
	ORNL SWSA 2 (1944- 1946)	SNSF
	Shefield, Illinois (1967-1978)	SNSF
	West Valley, New York (1963-1975)	SNSF

Notes on the table

Abbreviations: SNSF = Simple Near Surface Facility MC = Mined Cavity ENSF = Engineered Near Surface Facility GR = Geological Repository S/ENSF = SNSF and ENSF

[1]There are 77 repositories built to accommodate waste from Chernobyl accident.

[2]Repositories in Russian Federation started operation from 1961 to 1967.

[3]Waste was moved to another repository (respectively, from Solymar to RHFT Puspokszilagy; and from ORNL SWSA-1 to ORNL SWSA-2).

[4]Waste will be moved to a new repository (Himdalen) when constructed.

Definitions of selected terms

Low- and intermediate-level waste (LILW) is defined by the IAEA as radioactive wastes in which the concentration of or quantity of radionuclides is above clearance levels established by the regulatory body, but with a radionuclide content and thermal power below those of high-level waste (i.e. about 2 kW/m^3). LILW is often separated into short-lived and long-lived wastes. LILW arises from the operation of nuclear power plants (~500 m^3/GWe year) and other fuel cycle facilities (~90 m^3/GWe year from reprocessing, ~60 000 m^3/GWe year from uranium mining and milling), decommissioning of those facilities (5000 to 10 000 m^3 from a one megawatt-electric station), and applications of radioisotopes. These wastes require proper management through treatment and conditioning and ultimately through disposal.

Disposal is defined as the emplacement of waste in an approved, specified facility without the intention of retrieval. It may also include the approved direct discharge of effluents into the environment with subsequent dispersion (this article does not consider this aspect). Again, the disposal by confinement and isolation includes land disposal, sea dumping (which was implemented by some countries before it was banned by the London Dumping Convention), and others. (This article focuses on land disposal which is the prevailing current common practice.) In this context, the objective of disposal is to provide sufficient isolation of waste to protect humans and the environment and not to impose any undue burden on future generations. This can be fulfilled by applying multiple protective measures to the disposal system taking into account interdependencies among elements involved in the system (i.e. systems approach). The protective measures require several levels of protection and multiple barriers to isolate the waste and to limit releases of radioactive materials, and to ensure that failures or combinations of failures that might lead to significant radiological consequences are of a very low likelihood.

Near-surface facility is a nuclear facility for waste disposal located at or within a few tens of meters from the Earth's surface. These types of facilities include trenches and engineered vaults.

Mined cavities are near-surface facilities constructed inside mines and caverns.

Geological repository is a nuclear facility for waste disposal located underground (usually more than several hundred meters below the surface) in a stable geological formation to provide long-term isolation of radionuclides from the biosphere.

hole. Beginning in 1986 for safety reasons, the free space inside the vessels was filled with metal matrix or polymeric composite materials depending on the activity level and half-life of the spent SRS. Since 1995, the bore holes have been monitored to assess their performance. In the United States, spent SRS is categorized into different classes, and not all of them are acceptable for near-surface disposal. Consequently, more conservative disposal options, such as a geological repository or deep-augured holes are under consideration. Regardless of the technology used, the volume of spent SRS for this type of disposal may not be large enough to justify the economic or institutional costs associated with developing such a separate facility.

Improving existing disposal facilities. Some countries with existing disposal systems are improving the operation of or remediating their disposal facilities to enhance their protective capabilities or to meet new regulations. Remediation can involve the retrieval of waste, *in-situ* immobilization of waste, *in-situ* decontamination, and *in-situ* containment, such as installing cap, cutoff walls, or floor barriers. In a number of countries, including Germany, India, Bulgaria, and other countries in eastern Europe, safety assessments have been or will be done as part of overall reviews of the performance of existing disposal facilities.

At the Morsleben repository in Germany, for example, a safety assessment was done that resulted in the formulation of new waste acceptance requirements and quality-assurance procedures. In Hungary, the Puspokszilagy repository, which had been accepting some unconditioned waste together with packaged waste, has established a guideline to accept only waste packaged in 200-liter steel drums beginning in 1997. In the UK, the Drigg repository underwent major improvements in the late 1980s. Leaving the old simple trenches closed, a concrete vault was built for new types of waste packages. Cutoff walls also were installed to limit water flow in and out of the existing disposal trenches. In Norway, the remedial action plan at an old near-surface disposal facility for long-lived wastes involves digging out all waste packages, and storing them at an interim surface facility. They will be moved to a rock cavern storage and disposal facility to be built at Himdalen.

Long-term storage. In some countries, the option of long-term storage of radioactive wastes is beginning to emerge. The option delays a decision on the wastes' ultimate disposal, in efforts to gain public confidence for implementing disposal operations. However, the approach may require further considerations of regulatory and technical aspects.

At Norway's planned Himdalen site, horizontal tunnels are foreseen for disposal of short-lived LILW, as well as a separate tunnel for storage of wastes containing plutonium for an operational period of about 30 years during which the stored waste will not be retrieved. When the repository is closed, a decision will be made about the waste's disposal at the site, based on operational experience. A similar approach is seen in Switzerland where there is public concern over the irretrievability of waste to be disposed of at the planned Wellenberg repository. Authorities there are looking at the possibility of keeping the facility open and controlled for a period of two or more generations until the time when the decision about the repository's closure can be made.

Disposal costs. As disposal facilities have become technically more advanced, the costs of disposal have risen substantially. In some countries, there is a general noticeable trend to minimize the generation of radioactive wastes as part of cost-reduction efforts. Additionally, less expensive solutions are being sought for disposal of VLLW, as noted earlier.

Recently, a working group was formed with the Nuclear Energy Agency of the Organization for Economic Co-operation and Development on cost issues for LILW disposal. The group will identify cost components, analyze factors affecting disposal costs, and consider the impact of disposal costs on the overall price of generating electricity with nuclear power plants.

Public acceptance issues. As noted previously, the issue of public acceptance has heavily affected the process of radioactive waste management and disposal. In many countries, particularly industrialized ones, greater efforts are being made to overcome public perceptions that are strongly negative. They include enhanced communication programmes to improve dialogue with local communities and the public at large, and clearer demonstrations of a commitment to scientific excellence, environmental protection, and long-term safety in the siting and operation of repositories.

In some countries, financial incentives have been offered to communities accepting waste disposal sites. The compensation should not be considered as a risk premium, however, and safety issues must be discussed and resolved before starting any discussion on the compensation. Examples of financial incentives include monetary payment as well as provision of free electricity and greater employment opportunities.

Regional-multinational repositories. Some countries are expressing interest in establishing a regional-multinational repository whereby a site in a host country would accept radioactive wastes from other countries. The approach holds some economic, technological, and safety advantages, particularly for countries in the same geographical region. 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 wastes. The IAEA recently has assessed some of the major factors involved in the process of building consensus among interested countries on the various issues entailed in such a regional approach.

In principle, the basic issues involved in a regional-multinational repository are not much different from those related to national projects. But there are some qualitative differences related to the characteristics of the accepted wastes, the liability of partner countries, the division of responsibilities, the application of any required safeguards, and the ownership and transfer of waste materials.

Such regional repositories, which would build upon the best international practices in radioactive waste management, could give some countries the option of not building their own national sites, thereby holding down the total number of repositories worldwide. Additionally, they could provide an alternative for countries with unfavourable conditions for siting their own disposal sites. Disadvantages include the fact that a regional repository may increase transportation activities. It also may be difficult to establish a durable system which can survive changing political or institutional situations and which can assure the long-term collaboration of all partner countries. One of the most challenging tasks associated with such an approach is negotiating agreements which provide partner countries with assurances that all technical, political, and financial obligations will be fulfilled.

International co-operation

The disposal of low- and intermediate-level radioactive waste is based on proven and well-demonstrated technologies. If repositories are properly sited, constructed, and operated — and the radionuclide contents of the waste are controlled and limited — safety can be satisfactorily assured for long periods of time. This can be done by applying multiple protective measures, including engineered and natural barriers, and operational and institutional controls.

Within the IAEA's Member States, greater reliance is being placed upon multiple engineered barriers for safety and environmental protection, and for building public confidence. Additionally, emphasis is being placed on safe and reliable operation systems for remote handling, sheltering, and tracking of waste packages. At the same time, affordable solutions are being sought for the safe disposal of categories of wastes containing very low levels of radioactivity, whose volumes are large. Greater attention also is being given to issues related to the safe disposal of wastes containing naturally occurring radioactive materials, the management and disposal of spent sealed radiation sources, the costs of disposal, public acceptance, the improvement or remediation of existing disposal sites, the long-term safe storage of wastes, and the possible establishment of regional-multinational repositories.

Overall, countries, especially industrialized countries, are experiencing slow progress in developing new repositories with respect to their siting and licensing. These steps typically involve extensive technical reviews by the regulatory body, public hearings, and complex regulatory and legal procedures.

In developing countries, the situation is different. Most of them do not generate large amounts of radioactive wastes yet require technical assistance and guidance to establish sufficient infrastructures and capabilities for safely managing and disposing of wastes. Through its various technical and research programmes, the IAEA is supporting co-operative projects and activities toward these ends. As more radioactive waste disposal facilities are put into operation around the world, the transfer of technology and expertise to developing countries will continue to be of vital importance in helping them to build up their capabilities in this field.