CONF-8906240--1

IMPACT OF TECHNOLOGY APPLICATIONS TO THE MANAGEMENT OF LOW-LEVEL RADIOACTIVE WASTES*

CONF-8906240--1

DE90 002194

by

J.S. Devgun

Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439 U.S.A.

ABSTRACT

Low-level radioactive wastes are generated from reactor sources (nuclear power reactors) as well as from nonreactor sources (academic, medical, governmental, and industrial). In recent years, about 50,000 m^3 per year of such wastes have been generated in the United States and about 10,000 m^3 per year in Canada. Direct disposal of these wastes in shallow ground has been a favoured method in both countries in the past. In the United States, three operating commercial sites at Barnwell, South Carolina; Beatty, Nevada; and Richland, Washington, receive most of the commercial low-level waste generated. However, with recent advances in waste management, technologies are being applied to achieve optimum goals in terms of protection of human health and safety and the environment, as well as cost-effectiveness. These technologies must be applied from the generation sources through waste minimization and optimum segregation -- followed by waste processing, conditioning, storage, and disposal. A number of technologies that are available and can be applied as appropriate -- given the physical, chemical, and radiological characteristics of the waste -- include shredding, baling, compaction, supercompaction, decontamination, incineration, chemical treatment/conditioning, immobilization, and packaging. Interim and retrievable storage can be accomplished in a wide variety of storage structures, and several types of engineered disposal facility designs are now available. By applying an integrated approach to radioactive waste management, potential adverse impacts on human health and safety and the environment can be minimized.

*Work supported by U.S. Department of Energy, Assistant Secretary for Nuclear Energy, under Contract W-31-109-Eng-38.

INTRODUCTION

All types of hazardous wastes, including radioactive wastes, can have potential negative impacts on human health and safety and the environment. Solid radioactive wastes, which are usually low-activity wastes, account for the bulk of the total volume of radioactive wastes being generated. Although such wastes have generally been managed by various storage and disposal methods, a number of factors necessitate that an integrated management approach be applied from generation source to storage or disposal. Appropriate technologies can be applied at each step to achieve the ultimate objectives of safe and cost-effective storage or disposal. This paper briefly discusses waste sources, waste forms, and waste management practices, and provides a review of applicable technologies and their impacts from generation source to storage or disposal.

SOURCES OF LOW-LEVEL RADIOACTIVE WASTE

The term low-level radioactive waste (LLW) encompasses a wide variety of radioactive wastes and is generally defined on the basis of what it excludes rather than includes. In the United States, it is defined as radioactive waste not classified as high-level waste (HLW), transuranic waste (TRU), spent nuclear fuel, or uranium mill tailings. At the lower end of the LLW spectrum is the very-low-level radioactive waste classified as below regulatory concern (BRC) waste, whose activity typically ranges in $\mu Ci/m^3$. At the other end of the spectrum is the higher-activity waste, whose activity is typically as high as hundreds of Ci/m^3. The higher-activity LLW is categorized separately in Canada as intermediate-level radioactive waste (ILW).

Both reactor and nonreactor sources generate LLW. About half of the total volume of LLW produced from nondefense-related sources (waste from defense sources is outside the scope of this paper) comes from the operation of nuclear power reactors. At the end of 1988, 108 commercial nuclear power reactors were in operation in the United States (with an additional 7 units under construction) and 18 were in operation in Canada (with an additional 4 units under construction).[1] The nonreactor sources (academic, medical, governmental, and industrial) account for the remaining half of the total commercial waste generated. However, in the future, the proportion of nonreactor waste can be expected to increase because of the increased use of radioisotopes in research, medicine, and industry. The waste from decommissioning of aging nuclear reactors and facilities is also expected to become significant in the future. Currently, more than 20,000 organizations are licensed to use radioisotopes by the Nuclear Regulatory Commission (NRC) in the United States and more than 3,300 by the Atomic Energy Control Board (AECB) in Canada. Also, because of a de facto moratorium on the construction of nuclear power reactors due to public pressure, the proportion of the total LLW volume generated from the operation of reactors can be expected to remain stable or decrease as the reactor operators increasingly use volume reduction and waste processing.

WASTE FORMS, RADIONUCLIDE CONTENT, AND MANAGEMENT PRACTICES

Most LLW is solid or semisolid (wet solids). Liquid and gaseous wastes account for a relatively small fraction of the LLW volume and are not considered in this paper. The waste generated from reactor sources generally consists of spent ion-exchange resins, concentrated waste from evaporators, filter sludges, compactible trash, irradiated components, and contaminated plant hardware. The waste from nonreactor sources generally consists of compactible trash or solids, institutional/laboratory waste, liquid scintillation waste (as absorbed liquids), biological waste, animal carcasses, sealed sources, depleted uranium, and contaminated hardware. Most waste resulting from research and development activities, and from institutional activities, is in the form of contaminated clothing, rags, mopheads, and plastic and paper products. The typical radionuclides present in reactor and nonreactor wastes are given in Table 1.

Direct disposal of solid and liquid LLW into shallow ground has been practiced in both the United States and Canada. Past disposal practices were no different than sanitary landfill operations. In recent years, however, technologies for the management of these wastes have evolved significantly. Increased understanding of long-term hazards associated with many radionuclides, and increased regulatory and public concern for human health and safety and the environment, have also influenced the way these wastes are currently treated, stored, and disposed of.

WASTE MANAGEMENT PRACTICES AND THE NEED FOR TECHNOLOGY APPLICATIONS

The primary objective of any waste management practice for hazardous or radioactive waste is to protect human health and safety and the environment from potential negative impacts. The magnitude and type of potential impacts resulting from LLW will depend on the origin, nature, activity, and isotope content of the waste, as well as the siting and design of the storage or disposal facility. The application of appropriate technologies at each step from generation to disposal can minimize or prevent potential negative impacts from LLW. The application of technologies related to waste minimization, treatment, and storage or disposal has become a necessity because of the following factors:

- LLW can be disposed of only in facilities licensed to accept radioactive waste. Except for BRC waste, no radioactive waste can be sent to sanitary landfills.

- With increased societal concern regarding optimum use of land resources, and increased public opposition to the siting of hazardous waste facilities near their localities, the development of new facilities is an expensive, prolonged, and difficult process.

TABLE 1 Typical Radionuclides in Waste Streams from Reactor and Nonreactor Sources[a]

BWR[b]	PWR[b]	PHWR[c]	Academic	Medical	Industrial	Government
Cs-137	Co-60	H-3	Ca-45	P-32	P-32	P-32
Ba-137m	Cs-137	Co-60	Rb-86	C-14	Co-60	Cr-51
Co-60	Ba-137m	Cs-137	I-125	S-35	Th-230	Ni-63
Cs-134	Cs-134	Cr-51	P-32	Cr-51	U-238	Co-60
Mn-54	Co-58	Ce-144	C-14	Ca-45	I-125	H-3
Co-58	Mn-54	Zr-95	H-3	H-3	H-3	C-14
I-131	I-131	Nb-95	Sb-124	I-125	Cs-137	(dep) U
Others	Others	Zn-65	Sb-125m	Ir-192	Cs-134	
(C-14,	(C-14,	Ru-106	Ag-110m			
Tc-99,	Tc-99,	Cs-134				
I-129,	I-129,	Ce-141				
Ce-144,	Ce-144,	Ru-103				
etc.)	etc.)	Co-58				
			Fe-59			
			Sr-90			
			C-14			

[a]Data compiled from references 2-6.

[b]Radionuclides listed are for routine waste (i.e., resins, sludges, evaporator bottoms, compactible trash, noncompactible trash) from boiling water reactors (BWR) and pressurized water reactors (PWR). The nonroutine waste (e.g., irradiated components and decommissioning waste) can contain, in addition to the listed radionuclides, Fe-55, Ni-63, Ni-59, Sr-90, Cr-51, and Zn-65.

[c]It is estimated that each cubic metre of compacted LLW from a pressurized heavy water reactor (PHWR) type of CANDU (Canada, Deuterium, Uranium) reactors contains 8-11 Ci of H-3 and 1-5 μCi of C-14. The C-14 concentrations are about 0.25 Ci/m^3 for primary heat transport system resins and 130 Ci/m^3 for moderator resins.[5]

- With steep increases in LLW disposal costs during the past five years, reducing the waste volume offers great economic advantages.

- The regulatory criteria for each step in waste management (transportation, storage, and disposal) have lately become more restrictive.

- Because of increased public, political, and regulatory pressure, direct disposal of wastes into the ground (without any pretreatment, stabilization, or packaging) is not acceptable.

- Recent advances in various technologies suited to LLW management have made their application cost-effective and easier to implement.

- Optimum goals in terms of human health and safety and environmental protection can be achieved if waste management technologies are judiciously applied.

TECHNOLOGIES FOR SOLID LLW AND THEIR IMPACTS

The application of technologies must start at the waste generation source, and the whole system from generation to storage or disposal must be integrated. Relevant technologies can be grouped into four types: (1) volume reduction technologies, (2) chemical treatment/conditioning technologies, (3) waste packaging and waste storage technologies, and (4) disposal technologies. In the following discussion, the main technologies belonging to these four groups that are relevant to solid LLW are described. This information has been gleaned from the published literature as well as from operational experience at some LLW sites. The positive and/or negative impacts of the technologies are also discussed.

VOLUME REDUCTION TECHNOLOGIES

Waste Minimization

At industrial generation sources, waste minimization can sometimes be achieved by substituting different feedstock material, changing process technologies, or streamlining production processes. Waste minimization at most generation sources, however, is a question of management practices. The volume of waste generated can be effectively reduced through the implementation of new procedures, quality assurance programs, and programs to increase the general awareness of workers with regard to minimizing contaminated trash and avoiding cross-contamination of materials.

Compaction and Supercompaction

The volume of dry solid waste can also be reduced through the use of compactors, either hydraulic or pneumatic. The volume reduction achieved depends on the void space in the waste, its bulk density, its spring-back characteristics, and the force applied during compaction. Ordinary low-pressure compactors, where the applied force may be only a few tonnes, can provide a volume reduction factor of about 2 to 5 for contaminated trash waste. High-pressure compaction, also known as supercompaction, uses compaction forces of the order of 1,000 tonnes or more and can provide a volume reduction factor of about 6 to 10. It is also used for compacting waste-filled drums, which are flattened like pancakes. Compaction is a widely used technology at nuclear power plants, and it is also offered as a service by some companies through commercial mobile units.

Baling

Baling of solid LLW is generally carried out after compaction. Various types and sizes of baler units are available; however, rectangular bales are currently the most widely used technique for containerizing waste for storage or disposal. Baling of waste can also be used as an interim storage convenience for the combustible waste that will eventually be incinerated (for example, during shutdown periods of the incinerator).

Shredding

Shredding of contaminated paper, cloth, and plastic waste can result in a volume reduction of about 3:1. Shredding can also be used as a pretreatment step before incineration of combustible waste. Proper waste segregation is important because metallic pieces in the general trash have been often known to damage or break the cutting blades of shredders.

Cutting

Contaminated plant hardware can be cut into pieces for better packaging and storing. Often the discarded contaminated piping at nuclear reactor stations is sectioned with cutting equipment to fit into (and to reduce the empty volume of) transportation casks or storage containers. For this type of hardware, there is usually no intention of decontaminating and reusing the material. In addition to traditional saw cutting, specialized cutting technologies -- such as oxyacetylene cutting and plasma arc torch cutting -- can be used, as appropriate.

Incineration

If waste can be properly segregated at the source, incineration is perhaps the best option for dealing with combustible waste. It is estimated that about 50% of the solid waste generated at nuclear power facilities, the bulk of the waste generated as contaminated trash during research and development activities, and most of the biological waste (e.g., animal carcasses and contaminated laboratory waste) are combustible. A volume reduction of 100:1 or higher is not uncommon. The incinerator at Chalk River Nuclear Laboratories (CRNL) has achieved a volume reduction of about 170:1 (on as-received volume basis) for miscellaneous combustible uncompacted trash generated at the laboratories.[6-8] Incineration of baled waste has also been successfully implemented at the CRNL incinerator.[7] Radiochemical analysis of the resultant ash from the CRNL incinerator has shown that Co-60 and Cs-137 account for about 12 and 8% respectively of the total activity in the ash whereas other radionuclides (Sb-125, Cs-134, Ru-106, Ce-144, Ag-100m, Ce-141, Ru-103, Nb-95, Zr-95 and Zn-65) account for the remaining 80%. The activity in the ash is typically about 720 μCi/kg. Because of the radioactive decay of the shorter-lived radionuclides, after 2.5 years in storage, Co-60 and Cs-137 jointly account for about 85% (Co-60 52% and Cs-137 33%) of the total activity remaining in the ash; the other radionuclides account for about 15%. The activity remaining in the ash at this time is about 150 μCi/kg. Thus, the ash can be stored to allow a significant part of the radioactivity to decay.

Incineration technologies are well advanced, and various designs (such as starved-air incinerator, excess-air incineration, and pyrolytic or thermal decomposition) are commercially available. The ash or residue left from the incineration operation can be drummed for transportation and storage or can be immobilized through incorporation into matrices such as concrete or bitumen for disposal purposes.

CHEMICAL TREATMENT/CONDITIONING TECHNOLOGIES

Decontamination

Reusable equipment and hardware that is contaminated only on the surface, can be decontaminated, generally with various cleaning fluids. The big advantage of decontamination techniques is that, after decontamination, the equipment and hardware can be released for unrestricted use. This is even more important in the case of high-capital-cost equipment. The main disadvantage is the generation of liquid LLW that must then be appropriately managed. High-pressure-water-jetting techniques for decontamination are relatively inexpensive. For specialized decontamination applications, proprietary technologies are available, such as CAN-DECON (CANDU-Decontamination), CORD (Chemical Oxidation Reduction Decontamination), and LOMI (Low Oxidation State Metal Ion Reagents). Dry-cleaning techniques can also be used, e.g., method using Freon ($C_2F_3Cl_3$) and employing agitation by ultrasonic waves. Mechanical decontamination techniques include manual cleaning, vacuum cleaning, grinding, and machining.

Immobilization

Immobilization processes involve conversion of the waste (ash from incinerators, residues, liquid concentrates) into physically and chemically stable forms. Although volume reduction and pretreatment technologies -- such as incineration of solid LLW, chemical precipitation from liquid waste, and evaporation to concentrate liquid waste -- can be highly effective in achieving volume reduction, they also have the net effect of concentrating radionuclides in a small volume of the leftover waste. This concentrated radioactive waste material presents a higher potential for negative impacts on human health and the environment. This necessitates immobilization of these wastes into stabilized forms to reduce the potential for migration or dispersion of the radionuclides.

Generally, the waste is incorporated into a matrix from which the leaching of radionuclides can be expected to be negligible (under natural conditions) from either storage or disposal operations. Cementation processes have been widely used in the U.S. and abroad. Portland cements are the most commonly used matrix, but the use of high alumina cements, as well as pozzolanic cements is also becoming more widespread. Cements can also be used for immobilizing sludge and miscellaneous solid waste, and for embedding spent ion-exchange resins, decladding hulls, and contaminated hardware.

Bitumen has been employed as an immobilization agent in Canada and Europe. The bitumenization process generally involves heating asphalt (bitumen) to over 150°C, mixing the waste in it, and allowing it to cool and solidify.

Incorporation of radioactive waste into plastics is a relatively newer technology. The main plastic materials used for this purpose are polyethylene, urea-formaldehyde, polyester, and polystrene. For dry solid waste (generally the structural parts), a polymer-impregnated cement matrix has also been used as the embedding matrix.

Immobilization technologies, especially the cementation and bitumenization processes, are well developed. Extensive experience already exists for these processes with a variety of equipment, and the properties of the immobilized waste forms have been well studied in the United States, Canada, and Europe.

WASTE PACKAGING AND WASTE STORAGE TECHNOLOGIES

Packaging

Depending on the nature of the waste and the intended objective (e.g., transportation, storage, or disposal), packaging can vary from simple cardboard boxes to steel drums or concrete canisters. Packages can also vary in shape and size. The packaging of radioactive waste is used primarily for the purpose of transporting waste from the generation source to treatment, storage or disposal facility. The packages must meet the appropriate transportation regulations according to the classification of the waste. For storage purposes, the standard 210L steel drums are the most widely used packaging material. For long-term storage and disposal, packaging in steel or concrete canisters is used for higher-activity waste to provide radiation shielding and to act as an additional barrier to the potential migration or dispersion of radionuclides.

Storage Technologies

A variety of storage techniques and storage facility designs are currently being used for solid LLW. Storage is defined as the emplacement of waste with the intent to retrieve it at some later time. Disposal, on the other hand, means the emplacement of waste without any intention of subsequent retrieval, or, discharge and dispersal of the waste into the environment. Recently the concept of long-term storage has been gaining support in waste management circles. From a practical aspect, long-term storage can be considered a modified form of disposal where active management of the facility is not required (as in the case of a storage facility), but the facility is monitored and appropriate remedial actions (including retrieval of the waste, if necessary) are taken if radionuclide migration is detected. Storage practices currently in use are based on matching the waste characteristics (radiation hazard and physical/chemical characteristics) to an appropriate facility design. The applicable regulatory criteria are equally important.

For waste contaminated with only shorter-lived radionuclides, interim storage can be used to contain the waste until the radioactivity has decayed to background levels and the waste can be disposed of as nonradioactive waste. For most LLW, however, a certain portion of the radioactive content will outlive the design life of currently used storage structures (typically about 50 years). Thus, the waste will have to be retrieved and sent to a disposal facility. Storage facilities also supplant disposal facilities to accommodate surge situations resulting from mismatch of production, transportation, and disposal schedules.

In the United States, a large portion of solid LLW generated by utilities operating nuclear power plants and by other industrial sources is shipped to commercial LLW disposal sites, either directly or through broker firms (which run the collection and transportation services). A variety of storage techniques are also used at various generation sources. Storage facilities in Canada, especially those at the Bruce site of Ontario Hydro and the CRNL site of Atomic Energy of Canada Limited (AECL), provide illustrative examples of the technological developments in this area.[5-7, 9-10]

For most solid waste with radiation fields of less than 1 rem/h, aboveground concrete storage buildings provide a cost-effective storage facility. The waste is generally prepackaged, e.g., in drums or in stackable metal, concrete, or wood containers. The first storage building built at the Bruce site had a capacity of about 6,600 m^3 of packaged waste. Two other storage buildings have been added during the past five years. A storage building is also being used at the CRNL site for the storage of drummed waste from cleanup work conducted by AECL at a number of industrial/commercial properties.

For higher-activity waste, concrete trenches, concrete monoliths/radblocks, and concrete tile holes have been used at the CRNL and Bruce sites. Ontario Hydro has also developed quadricells, in-ground storage containers (ISCs), and large dry storage modules (DSMs).

Concrete trenches in shallow ground are used for storage of large quantities of relatively higher-activity solid LLW. The floor of the trenches is sloped to a sump to allow monitoring of the waste with respect to any potential water ingression into the trench. The filled trenches are covered with precast concrete lids. CRNL currently uses in-ground cylindrical bunkers built with reinforced concrete, typically 6 m in diameter and about 4 m deep for the storage of higher-activity LLW originating from medical/ industrial use of radioisotopes.

Radblocks can be manufactured off-site on a modular basis. They consist of portable concrete modules, each with four or five cylindrical cavities where waste components can be stored.

Concrete tile holes are used for high-activity LLW, such as spent cartridge filters and ion-exchange resins from nuclear reactors. The contact radiation field for waste accommodated in tile holes is less than 100 rem/h. Concrete tile holes are vertical in-ground facilities typically about 0.7 m in internal diameter and about 3.5 m deep, and they are built in arrays. Each tile hole can accommodate two ion-exchange columns or cartridge filters that can be directly bottom unloaded from the shielding flask into the tile hole. Loaded tile holes are backfilled with high slump concrete to form a monolithic cylindrical structure. Retrieval requires the removal of the one-piece tile hole monolith.

Quadricell is an aboveground storage structure designed to contain bulk quantities of ion-exchange resins that are collected at nuclear stations in large storage tanks. Quadricells can also accommodate highly radioactive reactor core components. Being totally aboveground, they have the advantage of being site-independent. Each quadricell module consists of two independent reinforced concrete barriers: (1) an approximately cubic structure, 6 m x 6 m x 5.5 m, that is internally separated into four cells; and (2) four inner cylindrical concrete vessels that are placed within the cells.

The ISCs can be constructed using vertical borehole augering techniques and utilize two (outer and inner) liners. The development of DSMs resulted from the fuel channel replacement project at Pickering Units 1 and 2 of Ontario Hydro. The waste generated from the retubing operations required large dry storage modules that could provide radiation shielding and accommodate full-length pressure tubes and calandria tubes. Each module weighs about 200 t but is still transferable and transportable.

DISPOSAL TECHNOLOGIES

Disposal of radioactive waste by burial of solid waste and discharge of liquid waste into the ground has been practiced in both the United States and Canada in the past, in many cases with unsatisfactory performance. The evolution of current disposal technologies owes much to the failures of the past. Radioactive plumes that migrated from these earlier disposal sites have been extensively monitored and have provided important data bases on the effectiveness of natural barriers, the importance of engineered barriers, and the need for the properly sited, properly engineered disposal facilities. The mobility of various radionuclides under varying disposal conditions has been well researched during the past 30 years.

Whereas the principle of dilute and disperse is applied in many cases for managing gaseous radioactive waste, and in some cases liquid radioactive waste, it is not applicable to the management of solid waste. Disposal of solid LLW is based on the principle of confinement. The higher-activity LLW, similar to HLW, must be isolated from the human environment for a long time. Most solid LLW is, however, low-activity waste and does not require a highly engineered facility intended to achieve long-term isolation of hazardous waste.

For well-segregated solid LLW, disposal in shallow-ground trenches can be a cost-effective means of disposal so long as human health and safety and the environment are protected. The success of shallow-ground disposal depends on the nature of the geologic medium, the site setting, the nature and form of the waste, and the site closure design.

In the United States, the three commercial radioactive waste disposal sites that are currently operating use shallow-ground disposal techniques. These sites -- Barnwell, South Carolina; Beatty, Nevada; Richland, Washington -- receive the bulk of the commercially generated solid LLW. In 1987, slightly more than 52,000 m^3 waste was received at these sites, with Barnwell receiving 52% of the total.[2]

The experience at these sites has not identified any problems related to site characteristics or disposal practices. The Beatty and Richland sites are located in arid regions whereas the Barnwell site is located in a humid region. At Barnwell, the unlined trenches dug in clayey soil (about 33% clay content) are typically 300 m long, 30 m wide, and 7 m deep. The base of the trenches is sloped and kept at least 1.5 m above the highest water table. A drain and collection system is used for sampling and monitoring; no migration of radionuclides has been observed. Packaged wastes are emplaced in the trench, and sandy soil is used to fill the void spaces between the packages. Filled trenches are covered with a minimum of 0.6 m of compacted clay, which in turn is covered by about 1 m of soil overburden. The topsoil cover is graded to promote runoff and then seeded with grass.

A variety of designs similar to the Barnwell site are being used or studied in the shallow-land disposal (SLD) concept, with variations in trench cover design, trench floor design, waste packaging, waste emplacement strategies, and sampling and monitoring equipment. One of the most important factors for the performance of shallow-land disposal facilities is the selection of a proper site. The problems experienced at several sites now closed (for example, Maxey Flats, Kentucky; West Valley, New York; and Sheffield, Illinois) can be traced to inadequate site characterization.[11,12]

Newer designs that have evolved as an alternative to simple shallow-land burial rely heavily on the engineered features of the facility rather than the natural characteristics of the site. A brief overview of such facilities is provided below.

Aboveground vaults (AGVs) are engineered concrete structures at grade level and are mostly site-indepenedent. They are designed to be intrusion-resistant and to withstand long-term weathering. The facility design generally consists of multiple disposal cells that are individually monitored for water releases. The concept is similar to the long-term storage concept and offers the advantages of comprehensive monitoring of any releases and allows remedial actions to be taken, if necessary. The design relies almost entirely on the integrity and longevity of the concrete structure, which leads to some technical uncertainty as to the long-term performance of the facility. Because of the potential for migration of radionuclides, through the surface water pathway and via direct dispersion in the environment, (in case of a breach of the facility), the potential impacts on human health and safety and the environment could be higher than if the vault is located below ground.

Belowground vaults (BGVs) are engineered concrete structures built below the ground surface. These vaults are designed to be compatible with local soil characteristics. The structures are intrusion-resistant and provide engineered barriers to potential radionuclide migration. Being located below ground, the soil provides an additional natural barrier to radionuclide migration, thus minimizing any potential impacts from release of radionuclides. The shell of the structure (walls and roof) is constructed of reinforced concrete, and the floor is either concrete or made of natural materials. For example, CRNL's intrusion-resistant underground structure (IRUS) will use a specially engineered floor of high-sorption capacity buffer materials.

The technology for earth-mounded concrete bunkers (EMCBs) has evolved from the French experience at Centre de La Manche.[13] In this case, concrete monoliths containing higher-activity LLW are buried a few meters below ground, and these monoliths provide a base for the above-ground structure (tumulus) containing lower-activity waste. The earthen cap of the facility is engineered to provide preventive barriers to the infiltration of water.

The concept of modular concrete canister disposal (MCCD) is similar to shallow-land disposal except that the waste is placed in individual modules of steel-reinforced concrete and the space between individual waste packages within the canister is filled with cement grout. This provides additional structural stability and additional barriers between the waste and the biosphere.

Mine cavities can also provide potential disposal sites for LLW. The concept involving deep mine cavities is being studied for HLW; for LLW, shallow-ground cavities can be suitable. However, the location of the mine cavity and its geologic and hydrogeologic setting are important factors.

Intermediate-depth disposal (IDD) is suitable for higher-activity LLW. It has been generally practiced (e.g., at Oak Ridge National Laboratory, Oak Ridge, Tenn) using shafts drilled about 100 m into the ground. Disposal at depth reduces the radiation levels at the ground surface and virtually eliminates the potential for inadvertent human intrusion. Shaft disposal is sometimes also referred to as greater confinement disposal (GCD). The Canadian concept for intermediate-depth disposal involves a facility constructed in rock at a depth of about 200 m to accommodate LLW for which the potential radiation hazard will remain even after 500 years.

Ocean disposal of LLW has been carried out by the United States and several European countries in the past (the United States ceased ocean disposal in 1970). Generally, the waste has been packaged in 210L drums, solidified into cement, and then dumped at various sites in the Atlantic and Pacific oceans. However, with an international consensus emerging against ocean dumping, this disposal practice is not a viable option for the future.

Repositories built by tunnelling crystalline rock under the sea is another alternative concept. This concept is being developed in Sweden for the Swedish final repository for reactor waste at Forsmark.

Other technologies cannot be considered viable concepts as yet. These include in-situ glassification, which is applicable to contaminated soils but has not yet been tried at actual waste sites and may not be cost-effective; transmutation of long-lived radionuclides into shorter-lived or stable isotopes; and disposal of radioactive wastes in outer space. Although such concepts could eventually become viable options for low-volume high-level radioactive waste, they are not expected to be cost-effective for managing LLW.

IMPACTS OF THE INTEGRATED APPROACH TO WASTE MANAGEMENT

Although application of appropriate technologies at each step in the waste management process is important, the key to successful radioactive waste management is the performance of the system as a whole. It is imperative that the system be treated in an integrated way to achieve optimum performance from waste storage or disposal. The potential negative impacts from radioactive waste on human health and safety and the environment can be minimized or mitigated only if a systems analysis approach is applied from generation source to disposal. A proposed strategy for solid LLW management and the application of technologies from generation source to disposal is shown in Figure 1.

Regulatory agencies generally apply the criterion to waste disposal in terms of the predicted resulting radiation dose to an individual from exposure to waste not exceeding certain pre-set limits. In the United States, the U.S. Nuclear Regulatory Commission's limit is 25 mrem per year to the whole body of an individual resulting from radioactive material that may be released to the general environment in groundwater, surface water, air, soil, plants, and animals. In Canada, the Atomic Energy Control Board has set this limit as 5 mrem/yr. The application of the ALARA (as low as reasonably achievable) principle is also required by many agencies as a matter of policy. To meet such criteria, the disposal facility and its near- and far-field environments, i.e., the site, must complement each other and the total disposal system must perform satisfactorily.[12]

In addition to health and safety issues, the costs of transportation, storage, and disposal necessitate that the amount of waste generated be minimized and that waste be properly segregated, volume reduced, and properly immobilized and packaged. Unfortunately, because of waste-specific, site-specific, and technology-specific aspects, only qualitative rather than quantitative assessment of such impacts can be made. A study of the waste volume reduction program at Ontario Hydro has estimated that greater than 60% of its total waste is considered combustible and greater than 20% is

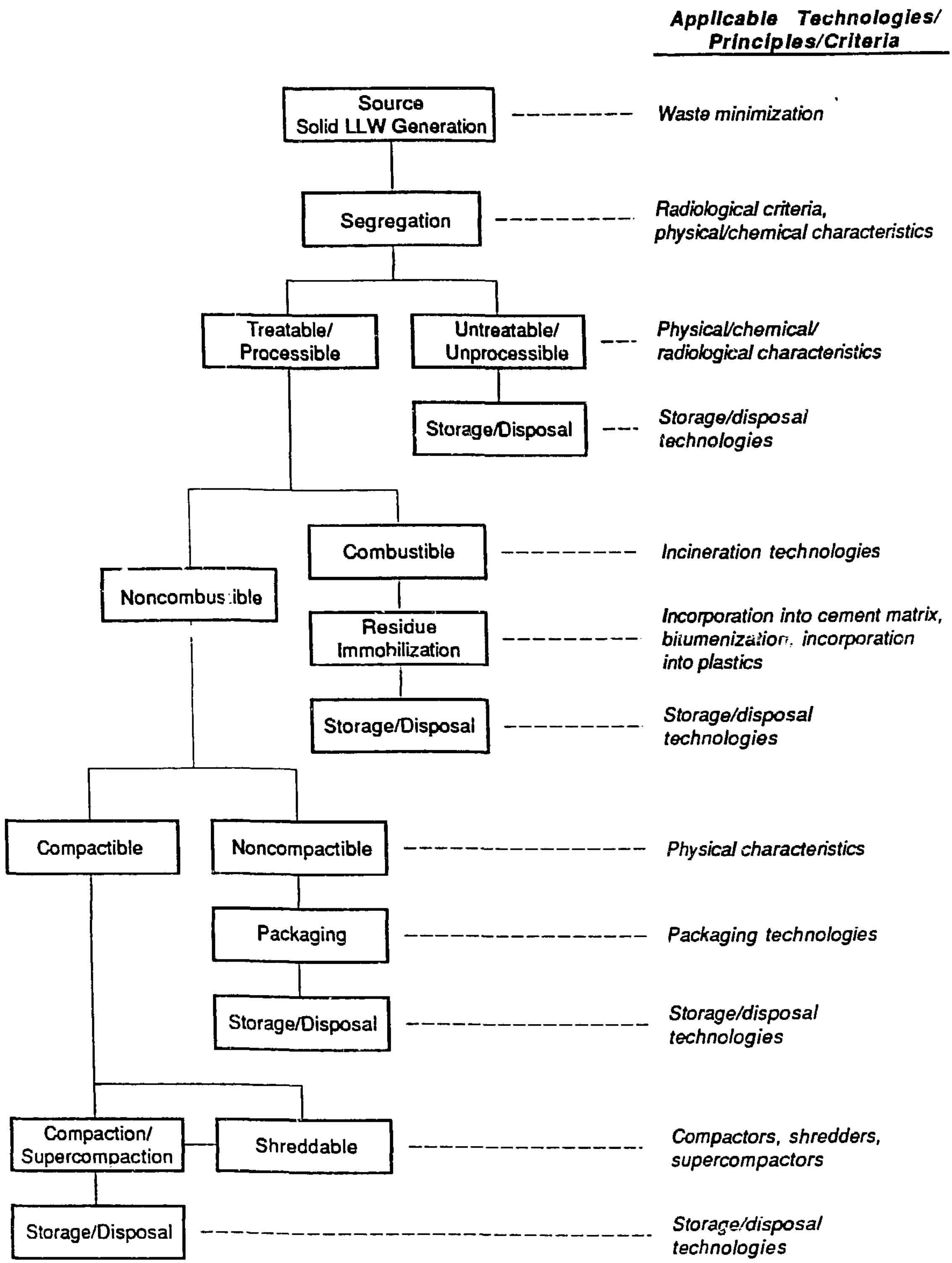

FIGURE 1 Strategy for Solid LLW Management from Source to Disposal.

considered compactible.[14] It is estimated that the final disposal cost of the no-processing option could be more than two times as expensive than if the appropriate segments of the waste were incinerated and compacted.

The capital (equipment) costs of some technology applications, such as supercompaction or incineration, are generally outside the means of small waste generators. However, waste minimization, optimum segregation, and compaction can be effectively utilized even by small producers. The collection agencies/companies can provide centralized waste-processing facilities or mobile waste-processing equipment on a rental basis.

The total waste volume received by all three operating commercial waste disposal sites in the United States has decreased steadily since 1981. From about 88,000 m^3 in 1981, the volume decreased to 75,000 m^3 in 1985 and to 52,000 m^3 in both 1986 and 1987.[2,3] This trend is at least partially due to an increase in the use of volume-reduction technologies by waste generators.

Disposal costs will continue to increase because of lack of disposal space and more stringent regulatory controls. This in itself provides an impetus to the increased use of waste-processing technologies. With better waste treatment technologies, engineering of storage and disposal systems, siting, and institutional controls, LLW can be managed in such a manner as to minimize any potential negative impacts on human health and safety and the environment.

CONCLUSIONS

Irrespective of the future of nuclear power in North America, LLW will continue to be generated from the increased use of radioisotopes and the decommissioning of aged nuclear facilities. Currently, nuclear power reactors account for about half of the commercial LLW generated. The LLW can be managed effectively and with minimum negative impacts on the human health and safety and the environment. A variety of technologies can be applied from the generation source to the disposal site. The whole system should be treated in an integrated way. It is important to differentiate the current LLW situation from the HLW situation where technologies and disposal concepts are still in the early stages of development. Technologies for LLW share some commonality with the municipal solid waste management techniques where an abundance of experience in some technologies already exists. Most of the applicable technologies are tried and proven technologies. Even the newer technologies are coming to maturity at an accelerated pace compared with the HLW disposal programs.

The potential radiation hazards posed by LLW can be minimized by transporting, storing, and disposing of the waste in appropriate waste forms, waste packages, and waste management facilities. Commercial LLW volumes are very small compared with the crisis proportions of municipal solid waste, which is being produced at 250 million tonnes a year in the United States.[15] A judicious application of available waste management technologies and methods can help keep the management of LLW from becoming a crisis situation.

REFERENCES

1. American Nuclear Society, Nuclear News, Vol. 32, No. 5, p. 80, April 1980.

2. U.S. Department of Energy, The 1987 State-By-State Assessment of Low-Level Radioactive Wastes Received at Commercial Disposal Sites, DOE/LLW-69T, December 1988.

3. U.S. Department of Energy, The 1985 State-by-State Assessment of low-level Radioactive Wastes Received at Commercial Disposal sites, DOE/LLW-59T, December 1986.

4. U.S. Department of Energy, Integrated Data Base for 1986: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics, DOE/RW-0006, Rev. 2, September 1986.

5. P.K.M. Rao, Ontario Hydro's Options for Long Term Management of Radioactive Wastes, Proceedings of the Second International Conference on Radioactive Waste Management, Canadian Nuclear Society, 1986 September 7-11, Winnipeg, Manitoba, Canada, p. 775-781, ISBN-0-919784-08-9.

6. D.G. Hardy, D.F. Dixon, J.S. Devgun and R.G. Jarvis, Concept Safety Assessment of a Prototype, Intrusion-Resistant, Shallow Land Burial Facility for the Permanent Disposal of Low- and Intermediate-Level Radioactive Waste, Atomic Energy of Canada Limited Report, AECL-MISC-277, NSAC Ref. #56-54, Chalk River Nuclear Laboratories, Chalk River, Ontario, September 1987.

7. J.S. Devgun (editor), Activities Related to Low-level Radioactive Waste Management at AECL's Nuclear Research sites, Atomic Energy of Canada Limited report TR-360-2, Chalk River Nuclear Laboratories, Chalk River, Ontario, Canada, March 1987.

8. N.Y. Beamer, Experience with Low-level Waste Incineration at Chalk River Nuclear Laboratories, Proceedings of Waste Management '84, March 11-15, 1984, Tucson, Arizona, Vol. 2, p. 205-212, 1984.

9. T.J. Carter and P.K.M. Rao, Fifteen years of Radioactive Waste Management at Ontario Hydro, Proceedings of Waste Management '85, March 24-28, 1985, Tucson, Arizona, Vol. 2, p. 445-451, 1985.

10. J.S. Devgun, Minutes of the 11th INEX Meeting (August 18, 1987) on Low- and Intermediate-Level Radioactive Waste Management, Atomic Energy of Canada Limited report LILW-11, (not a formal publication), available from Chalk River Nuclear Laboratories, Chalk River, Ontario, Canada, February 1988.

11. J.S. Devgun, Site Considerations and Requirements for Low- and Intermediate-Level Radioactive Waste Management, Presented at the IAEA Interregional Training Course on Management and Disposal of Radioactive Wastes, Canada, May 26-June 13, 1986. Available as Atomic Energy of Canada Limited report AECL-9109, Chalk River Nuclear Laboratories, Chalk River, Ontario, Canada.

12. J.S. Devgun and D.H. Charlesworth, Impact of Past Experiences on Engineering a Shallow Land Burial Facility, Proceedings of Waste Management '87, March 1-5, 1987, Tucson, Arizona, Vol. 3, p. 205-212, 1987.

13. F. Van Kote, 12 Years of Experience of Shallow Land Disposal of Low and Intermediate Level Radioactive Waste in France, Proceedings of the Symposium on Low-Level Waste Disposal, Facility Design, Construction, and Operating Practices, NUREG/CP-0028, Vol. 3, p. 177-200, CONF-820911, 1982.

14. R. Kohout and L.M. Calzolari, Considerations in Reviewing the Waste Volume Reduction Program in a Large Utility, Proceedings of Waste Management '87, March 1-5, 1987, Tucson, Arizona, Vol. 3, p. 13-21, 1987.

15. J. Glenn and D. Riggle, Where Does the Waste Go?, Biocycle (J. of Waste Recycling), Vol. 30, No. 4 , p. 34-39, April 1989.