BNL 31650

CONF-820424--33

BNL--31650

DE82 020024

CURRENT STATUS OF LOW-LEVEL-WASTE-SEGREGATION TECHNOLOGY

by

D.E. Clark, P. Colombo, and V.L. Sailor

Nuclear Waste Research Group
Department of Nuclear Energy
Brookhaven National Laboratory
Associated Universities, Inc.
Upton, New York 11973

-EB

Paper presented at ANS Topical Meeting on: The Treatment and Handling of Radioactive Wastes, April 19-22, Richland, Washington. This work was supported by the U.S. Department of Energy Low-Level Waste Management Program.

CURRENT STATUS OF LOW-LEVEL-WASTE-SEGREGATION TECHNOLOGY

D. E. Clark, P. Colombo and V. L. Sailor
Nuclear Waste Research Group
Department of Nuclear-Energy
Brookhaven National Laboratory
Upton, New York 11973

ABSTRACT

The adoption of improved waste segregation practices by waste generators and burial sites will result in the improved disposal of low-level wastes (LLW) in the future. While very little waste segregation has been practiced at LLW burial sites in the past, it is now recognized that many of the problems connected with this disposal mode are directly attributable to or aggravated by the indiscriminate mixing of various waste types in the burial trenches. Thus, subsidence effects, contact with ground fluids, movement of radioactivity in the vapor phase, migration of radionuclides due to the presence of chelating agents or products of biological degradation, deleterious chemical reactions, and other problems have occurred. Regulations are currently being promulgated which will require waste segregation to a high degree at LLW burial sites. This assures that waste segregation technology will also be adopted by individual waste generators or processors in the future.

The state-of-the-art of LLW segregation technology and current practices in the U.S.A. have been surveyed at representative facilities. Favorable experience has been reported at various sites following the application of segregation controls. Efficient segregation of nonradioactive waste from radioactive wastes at the point of generation can drastically reduce the volume and cost of waste requiring treatment and disposal. Segregation of wastes can also lead to more efficient waste processing by which, for example, personnel exposures can be reduced and solidification can be directed towards certain "problem" wastes. This paper reports on the state-of-the-art survey and addresses current and projected LLW segregation practices and their relationship to other waste management activities.

INTRODUCTION

A survey has been made of waste segregation technology as currently applied to the management of low-level wastes (LLW) in the U.S.A. Present-day waste segregation practices were ascertained through a review of the recent literature and by means of personal interviews with personnel at selected facilities. These survey data were used to analyze the relationship between waste segregation practices and waste treatment/disposal processes, to assess the developmental needs for improved segregation technology, and to evaluate the costs and benefits associated with the implementation of waste segregation controls.

The management of LLW involves a series of unit operations as shown in Figure 1. To a varying degree, waste segregation may be applied at any of the stages indicated in Figure 1. However, segregation is best accomplished early on and as close to the point of generation as is technically feasible. It then will serve as a key determinant of all subsequent operations (i.e., waste treatment and processing, interim storage, transportation and final disposition of LLW).

POTENTIAL BENEFITS OF WASTE SEGREGATION

There are many potential benefits that may be derived from greater use of waste segregation technology at the LLW generating facilities and disposal sites. These include reductions in cost and radiation exposures to personnel, as well as an enhanced ability to adopt volume reduction and other advanced waste treatment options.

The segregation or separating out of radioactive waste streams by the LLW generator can produce a number of direct benefits. Segregation of nonradioactive waste from radioactive wastes at the source can drastically reduce the volume of waste requiring costly waste treatment and disposal. Segregation of wastes can also lead to more efficient waste processing and packaging.

Although little waste segregation has been practiced at LLW burial sites in the past, it is now recognized that many of the problems connected with this disposal mode are directly attributable to or aggravated by the indiscriminate mixing of various waste types in the burial trenches. For example, organic chelating materials have been buried in the same trenches as solidified wastes, providing a mode for radionuclide migration. Corrosive compounds, frequently present, promote a rapid loss of integrity of metallic waste containers. Other chemical interactions may also occur when diverse waste types are buried in close proximity without regard to segregation. Subsidence and trench cap deterioration may be minimized by segregation of organic solid wastes susceptible to microbial decomposition and compaction under the weight of the overburden.

MANDATORY REQUIREMENTS FOR WASTE SEGREGATION

At the present time, there are only a few mandatory requirements for segregation of LLW. However, this situation is rapidly changing, and there appears to be little doubt that more segregation controls will be mandated for LLW in the future.

In 1981, the Nuclear Regulatory Commission (NRC) published draft regulations regarding acceptable disposal practices for burial of commercially generated LLW in the future.[1] It may be anticipated that disposal site segregation controls will be imposed in the future to permit the application of specific disposal methods or use of specific site locations for LLW based upon waste characteristics such as type, form, chemical composition, and radionuclide content. The imposition of these segregation controls at the burial sites will require that the generators of LLW make greater use of segregation technology.

METHODOLOGY OF THIS STUDY

The methodology used for this study included a survey of the pertinent literature, personal interviews with waste managers, and site visits to selected facilities. Survey information was obtained on generation rates and characteristics of LLW produced at each facility, waste collection and handling practices, current or anticipated use of waste segregation technology, available cost information, on-site treatment and packaging of the wastes, and final disposition of the packaged LLW. Included among the sites surveyed for their waste segregation practices were selected Department of Energy (DOE) laboratories and plants; fuel fabrication plants; research and commercial power reactors; institutions such as universities, hospitals, and medical research centers; industrial concerns such as radioisotope and radiopharmaceutical producers; waste brokers and processors; and LLW disposal sites, both DOE and commercial.

CURRENT WASTE SEGREGATION PRACTICES

Many LLW generators practice some degree of segregation of their various waste streams, although the terminology "waste segregation" does not appear to be in common usage. Because of the rapidly increasing costs of LLW disposal and restrictions which have been imposed over the past two years at commercially operated shallow land burial sites, there has been an increasing interest in technologies to reduce the volumes of LLW which must be shipped for disposal. Volume reduction treatments are specific to certain waste types, and consequently require segregation as a pretreatment. Thus, the technology and requirements for waste segregation are now undergoing rapid change.

Waste segregation can be utilized for the exercise of different disposal options. The recent NRC changes in 10 CFR 20, which allow for the disposal of certain biomedical waste "without regard to its radioactivity,"[2] have already resulted in a significant reduction in the volumes of LLW shipped from several institutions.

Liquid waste streams are frequently combined for processing purposes; in such cases, any segregation required as a pretreatment is based on considerations for improved processing and the obtaining of acceptable waste form. For example, at nuclear power plants, high conductivity waste streams are usually combined for common processing by evaporation, and low conductivity waste streams are combined for treatment by ion exchange. In general, wet organic and aqueous LLWs are segregated wherever possible (special solidification techniques are normally required for organic liquids). Low-activity and high-activity liquid waste streams are usually processed separately.

Because of their heterogeneous nature, solid LLW streams may present a formidable challenge to successful segregation within the framework of acceptable cost (both economic and radiologic). Trigilio[3] has discussed methods used to segregate solid wastes into constituents amenable to further treatment, including hand sorting, shredding, and air classification systems.

DOE LABORATORIES AND PLANTS

Waste-producing activities at various DOE laboratories and plants include nuclear fuel preparation; development, testing and irradiation of nuclear fuels and advanced reactor components; examination of irradiated materials; the operation of nuclear reactors and charged-particle accelerators; facility decontamination and decommissioning (D&D); radioactive waste management operations; plus a wide assortment of nuclear-related research and development (R&D) activities.

The DOE-generated LLWs arise as gases, liquids, and wet or dry solids, and may receive further treatment or processing as appropriate prior to disposal. Details concerning the generation, treatment, handling, packaging, and disposition of DOE-generated LLWs at different sites have been published previously.[4-11]

At Oak Ridge National Laboratory (ORNL), a comprehensive waste segregation program has been implemented.[12] This program has been quite successful due largely to dedicated efforts for increasing worker awareness of the need to segregate all solid wastes and to reduce as much as practicable the volume of LLW requiring costly treatment and burial. To a varying degree, similar practices have been adopted at other DOE facilities. However, because of the great success of the ORNL program, it is spotlighted as a worthy model for all other similar sites. The ORNL effort has included the coordinated use of seminars and training sessions, publications of articles in the laboratory paper, and dissemination of attractive posters throughout the laboratory.[12]

It is the responsibility of the individual LLW generator at ORNL to assure that radioactive wastes are properly segregated, decontaminated or contained, monitored and labeled for disposal in accordance with the laboratory rules. Health Physics personnel provide consultation, surveying and monitoring, and other services as needed for proper management of the LLW, including periodic, unscheduled on-site team inspection of waste to ensure proper segregation. Health Physics personnel also control all of the keys to locked dumpsters used to collect LLW, and they perform individual spot checks as necessary.

At ORNL, wastes are segregated into the following categories:

- noncontaminated waste (6 different classes)
- general high-level radioactive waste
- general low-level radioactive waste
- general low-level radioactive compactible waste

- general low-level radioactive noncompactible waste
- ^{233}U/transuranic waste
- ^{235}U waste
- mixed radioactive wastes
- low-hazard contaminated waste

Each of these categories is further defined in the ORNL operational guidelines. Very little is required in the way of segregation for liquid wastes at ORNL. These wastes are collected in holding tanks and disposed of on a regular batch basis by hydrofracture injection into the underlying shale structures located hundreds of meters below the laboratory site.[11]

As alternate or advanced treatment technologies for LLW at DOE facilities are adopted, the implementation of additional segregation controls may be required. For example, the planned installation of a smelter facility at Idaho Engineering Development Laboratory (INEL) for the treatment of metallic LLW, plus an incinerator for combustible LLW, will require segregation of metallic from nonmetallic, and combustible from noncombustible wastes. At ORNL, another option (with implications for segregation) for processing solid LLW is under study.[11] This treatment would involve the production of waste pellets of 1/8-inch diameter, 1/2-inch maximum length, for injection by hydrofracture along with liquid wastes produced at ORNL. The preconceptual design for this processing facility includes a stage for mechanically sorting out (i.e., segregating) metals and nonpelletizable material from the waste feed stream.

FUEL CYCLE FACILITIES

The generation of LLW occurs as a necessary by-product of all phases of the nuclear fuel cycle. With the continuing absence of commercial fuel reprocessing activities in the U.S.A., LLW-generating facilities consist of nuclear fuel preparation/fabrication plants and nuclear power plants.

Most of the liquid wastes arising from the fabrication of nuclear fuels (uranium-contaminated wastes) are pumped into evaporation ponds on site. The liquid wastes are sometimes segregated by activity and placed in different ponds. Solid wastes are usually segregated into economically recoverable or non-economically recoverable uranium fractions. Some plants plan to eventually recycle all waste materials so that no off-site shipments would be required. Such plans call for extensive decontamination and scrap recovery operations to be instituted at the plants. Waste streams would be segregated by enrichment bands (differing by 1% enrichment or so) and by phase or form (e.g., fluoride sludges would be segregated from nitrate sludges, etc.) for in-plant processing.

Considerable quantities of LLW are produced at nuclear power plants. Detailed information concerning reactor wastes and their management has been presented in References 4, 13 and 14.

Most of the nuclear power plants included in our survey report that they have had few requirements for waste segregation in the past, but that this situation is changing because of steadily increasing disposal costs and decreasing disposal quotas. Segregation of solid wastes into radioactive and nonradioactive fractions has been reasonably successful at most plants, but only when done with the use of single check points that can be continuously monitored. The general experience with sorting mixed batches of waste into radioactive and nonradioactive fractions appears to have been that too much cross-contamination occurs. Improved housekeeping and employee training are receiving increased attention at all of the plants which were surveyed.

Quaka[15] has reported on the importance of segregating incoming water streams according to activity and conductivity at the Dresden Station liquid radwaste process facility. It was noted that all input flow paths to the various radwaste collection tanks should provide for monitoring and identification.

At nuclear power plants, the concept of on-site storage with corresponding requirements for segregation of all LLW is now being seriously considered. Tennessee Valley Authority (TVA), for example, has constructed an on-site storage facility and is hopeful of eventually receiving approval for indefinite storage of its LLW.[16]

NON-FUEL CYCLE FACILITIES

Non-fuel cycle facilities include nuclear research centers; institutions such as universities, hospitals and medical research centers; and industrial facilities such as associated with production of radioisotopes and labeled compounds. Industrial and institutional LLWs are produced in all 50 states and the District of Columbia. A recent count of licensees indicated that there were 6,415 institutions (medical facilities and universities), and 10,961 industrial concerns licensed to use radioisotopes (and therefore potential generators of LLW). A study of non-fuel cycle wastes generated in the late 1970's indicated that on a volume basis 8% were from academic sources, 65% from medical sources, and 27% from industrial sources.[17] It has been reported that over 58% of the non-fuel cycle waste licensees do not use commercial burial facilities as the primary disposal mode.[17] Instead, they use decay to nonradioactive levels, incineration, or on-site burial.

Several authors[18-20] have discussed the disposal problems posed by institutional or biomedical wastes which largely contain low levels of short-lived radionuclides. Briner[20] has proposed the use of segregation controls, where suitable, for alternate disposal options such as on-site holding for decay. In the NRC-regulated states, special license approval under 10 CFR 20.302 is required in order to hold radioactive materials for decay prior to disposal as ordinary trash. For the burial of small quantities of radioactive materials on a licensee's site, a license amendment may be sought under provisions of a new rule effective February 1981 in 10 CFR 20.302. The disposal of radioactive liquids in sanitary sewage is governed under 10 CFR 20.303, and any volume reduction treatments such as compaction or incineration are covered under 10 CFR 20.305. The recently adopted 10 CFR 20.306 permits disposal as non-radioactive material of certain animal and liquid scintillation wastes containing ^{3}H and ^{14}C.

The most widely practiced segregation treatment at institutions is to separate the wastes according to half-life of the radioactive contaminants. Most of the institutions surveyed require users to segregate LLWs into the categories: biological, liquid scintillation, dry solid, aqueous liquid, and organic liquid. Segregation is also maintained for incompatible wastes and for those with special hazards (e.g., carcinogens).

As an alternative disposal option for non-fuel cycle wastes, there appears to be growing interest in incineration.[21] NRC regulations permit this option under 10 CFR 20.305, provided that the effluent concentrations are in accordance with requirements of 10 CFR 20.106 and that all state and local regulations are met. This option is expected to become more attractive as the technology has improved markedly in recent years, and it is becoming more cost-effective. Pretreatment requirements for efficient incineration include segregation of wastes by BTU content (e.g., dry solids separated from aqueous wastes, etc.) and by radionuclide content. While some isotopes are good candidates for incineration (e.g., ^{3}H, ^{14}C, ^{51}Cr, ^{55}Fe, ^{57}Co, etc.), others are better held for decay (e.g., those with half-lives of less than 30 days or so), and still others probably should not be incinerated (e.g., radioiodine).

Most institutions report having had few problems in managing their LLW other than the steadily increasing cost of disposal and the widespread concern that due to a minor infraction of the rules (or the gross miscalculation of an individual) they could be excluded from the LLW burial sites. The driving force for adopting waste segregation or other conservative management practices beyond what is required by regulations is largely economic. Current disposal costs for institutional wastes appear to be averaging upwards of $175 for a 55-gallon (208-liter) drum. For the small LLW generator, there is little if any incentive for practicing waste segregation, however, since he may produce only an occasional drum of waste.

Many of the small institutional and private generators of LLW rely upon waste brokers for the routine pickup of packaged wastes for ultimate delivery to a LLW disposal site. Waste brokers vary widely in size and frequently may service generators of toxic chemical wastes as well as LLW. In general, these firms apply little in the way of segregation in their handling and treatment of LLWs.

Although industrial LLW has not been well characterized, it is probable that radiopharmaceutical wastes represent a major component. Such wastes are primarily organic compounds labeled with relatively long-lived radionuclides such as ^{35}S, ^{3}H, ^{135}I, and ^{14}C.

Waste segregation practices vary greatly among different industrial concerns, but tend to be similar for companies of the same type. Thus, high-specific activity wastes are nearly always segregated at those facilities which produce LLW having a wide range of radioactivity concentrations. For producers of radioisotopes, labeled compounds, assay kits and similar products for biomedical and physical research purposes, waste segregation becomes very important as a basis for radioactive waste processing. A study was made of the segregation practices at a large company representative of this type (New England Nuclear) which could serve as a model for other facilities.

At New England Nuclear, segregation of radioactive wastes is practiced to a high degree. This has been accomplished largely through the implementation of institutional controls and increasing employee awareness of the need for waste segregation. For the most part, segregation occurs at the point of generation and is the responsibility of the waste generator. Radioactive wastes are separated into seven (7) distinct categories, as follows:

Category A	Dry-solid radioactive waste
Category B	Absorbed liquid radioactive waste
Category C	Liquid radioactive waste
Category D	Noncompactible radioactive waste
Category E	Animal and biological radioactive waste
Category F	Radioactive material requiring special handling and/or packaging
Category G	Short-lived materials to be held for decay

Within these categories, the wastes are further segregated according to activity and radioisotopic contamination, and organics are segregated as organic acids, oil, liquid scintillation mixtures, and solvents (all others).

An important feature of the waste management plan at New England Nuclear is the careful documentation of the nature and origin of all radioactive waste generated by laboratory personnel. A cradle-to-grave system of documentation is used in which it is possible to trace the origin of a particular radioactive waste unit back to a particular laboratory and employee.

A special procedure is in use at New England Nuclear for inspecting laboratory wastes before they are compacted. These wastes contain predominantly ^{3}H, ^{14}C or ^{35}S and present very little radiation hazard when packaged as bagged LLW in 55-gallon (208-liter) drums collected from the laboratories. Using a mechanical drum tilting device and a sorting table, the contents of each drum are handled and inspected under controlled radiological conditions by personnel familiar with LLW acceptance criteria for the burial site. If acceptable, the bagged wastes are then placed in another drum and are compacted.

Each year at New England Nuclear, approximately 1,000 drums (55-gallon/208-liter size) of LLW are placed in storage for decay for a minimum of 10 half-lives. These wastes, segregated at the points of origin, are contaminated with radionuclides from one of the following groups: ^{201}Tl, ^{67}Ga, ^{99}Mo, ^{99m}Tc; or ^{32}P, ^{131}I; or ^{133}Xe.

LLW DISPOSAL SITES

In general, there are two types of shallow land burial sites used for disposal of LLW: arid sites and humid sites. Of the six major DOE burial sites, four are classified as arid (Idaho National Engineering Laboratory, Hanford Site, Nevada Test Site, and Los Alamos National Laboratory), and two are humid (Oak Ridge National Laboratory and Savannah River Plant). Of the three currently operating commercial sites, two are classified as arid (Beatty, Nevada and Richland, Washington), and one is humid (Barnwell, South Carolina). The distinguishing feature between these two types of burial sites is the annual precipitation, which becomes important in terms of potential contact with the buried wastes.

At arid burial sites, LLW with very high radiation levels is frequently segregated from other wastes and disposed of by placement in deep shafts. This normally presents no particular problem since the trenches are well above groundwater levels.

At humid sites, the distance between the buried wastes and the water table is relatively small, and the distance to points of groundwater discharge to the surface water is relatively short. However, the large volumes of surface-water flow do provide a considerable measure of dilution once contamination has reached the surface-water system. In contrast to arid sites, erosion control normally can be maintained at humid sites with a minimal surface maintenance effort. Because of the greater potential for contact of buried wastes with water at humid sites, the segregation of incompatible wastes is much more important than at arid sites.

At the Barnwell site, high activity wastes are disposed of in split trenches where personnel radiation exposures can be minimized by use of remote handling techniques. Organic medical wastes and some chemical wastes (e.g., CaF_2) are segregated within individual trenches. Wastes containing ^{235}U may require separation within individual trenches due to criticality considerations. Fuel cycle and non-fuel cycle LLWs are also segregated by placement in different trenches. The Barnwell site will no longer accept toluene, xylene, dioxane, scintillation liquids or other organic liquids with similar chemical properties; nor will the site accept any containers which have at any time contained any of these liquids.

COSTS ASSOCIATED WITH WASTE SEGREGATION

In general, the establishment of waste segregation controls by generators and handlers of LLW should involve fairly minimal expenditures.

It is expected that little additional expense would be required for radiation survey and monitoring instrumentation beyond what would already be available at the facility. Large-sized instrumentation (e.g., drum assay systems) would only be added to a facility if justified on the basis of the quantity of waste handled or the economic value of recoverable materials such as radionuclides for recycle. The redesign of a waste management system would perhaps involve the acquisition of waste containers and handling/processing systems of varying complexity. However, this should require only a modest outlay in comparison with the overall LLW management budget. Most of the technology for waste segregation is relatively inexpensive and its adoption should not be greatly burdensome.

Very little cost information was obtained in this survey of LLW segregation practices. It is frequently the case that waste segregation has been accomplished largely through the establishment of institutional controls and dedication on the part of the concerned parties. Waste segregation may primarily involve visual-manual type operations on the part of LLW generators and other workers. Thus, the assignment of economic cost to the adoption of waste segregation practices is understandably imprecise. Likewise, the assignment of radiologic costs arising from increased handling operations and consequent exposure to ionizing radiation is imprecise, and a proper evaluation would require considerable study of each situation.

Many facilities have reported cost savings resulting from adoption of segregation practices, in particular where LLW volumes have been reduced through segregation of nonradioactive from radioactive wastes. Significant savings are also possible where LLW containing short-lived radioactivity is stored on-site for decay to nonradioactive levels, where certain ^{3}H and ^{14}C-containing wastes are alternatively disposed of, and where suspected transuranic ("suspect-TRU") wastes can be shown to be LLW rather than TRU wastes (disposal costs for LLW are much less than for TRU wastes).

RECOMMENDATIONS

Enchanced LLW segregation practices should be established at shallow land burial sites, provided that the accruing benefits are reasonably in line with the incremental operational costs (e.g., if the acceptance of potential increases in radiation exposure to the site personnel due to increased handling can be justified). Segregation and good housekeeping at the source of LLW production should be utilized to keep the contamination of nonradioactive waste to the lowest practicable level, and to facilitate placing waste into suitable categories for particular burial facilities.

Several types of waste should receive special treatment to immobilize the radionuclides, to reduce the hazard from chemically toxic materials, and to reduce handling risks in transportation and disposal. Special segregation is needed for LLW containing or capable of producing organic chelating agents, and for biological wastes that can undergo bacterial decomposition yielding organic acids, gases, and other undesirable products. Segregation is also recommended for combustible wastes and for those containing long-lived radionuclides, isotopes of high radiotoxicity, high specific activity, and certain wastes such as unsolidified spent ion exchange resin.

The following abbreviated list of specific actions for improving LLW segregation practices should be considered by the appropriate parties:

- prepare a "Manual on Waste Segregation Technologies"
- develop an appropriate waste classification system
- apply computer techniques to the characterization and tracking of LLW waste streams
- improve procedures for assay of waste units
- apply administrative controls to a greater degree (e.g., redefine radiation zones and exert more control over materials that may become contaminated)
- define "de minimus" levels of radioactivity for solids
- make greater use of technology for segregating "suspect-TRU" wastes into LLW and TRU wastes
- make greater use of alternate disposal options (such as storing on-site for decay)
- establish centralized LLW treatment facilities to service multiple small users of radioisotopes
- perform additional study of segregation needs for D&D and other advanced treatment technologies
- disseminate information on waste segregation to the LLW community

SUMMARY AND CONCLUSIONS

The current status of LLW segregation technology has been ascertained. Practices vary from no segregation to a high degree of segregation where it has been shown to be cost-effective or required as pretreatment to other waste treatments. Waste segregation has potential for reducing disposal costs and radiation exposure to personnel (except at the burial sites where there might be increased exposures due to increased handling). The greater use of waste segregation technology can lead to more efficient waste processing, improved operations and disposal practices at the burial sites, subsidence control, better containment of radioactivity, and a generally much more streamlined waste management system.

REFERENCES

1. U. S. Nuclear Regulatory Commission, "Licensing Requirements for Land Disposal of Radioactive Waste: 10 CFR 2, 19, 20, 21, 30, 40, 51, 61, 70, 73 and 170," pp. 38081-38108, Federal Register, 46, No. 142 (July 24, 1981).

2. U. S. Nuclear Regulatory Commission, "Biomedical Waste Disposal: 10 CFR Part 20," pp. 16230-16234, Federal Register, 46, No. 47 (March 11, 1981).

3. G. Trigilio, Volume Reduction Techniques in Low-Level Radioactive Waste, NUREG/CR-2206, Teknekron, Inc., Berkeley, California (September 1981).

4. A. H. Kibbey and H. W. Godbee, A State-of-the-Art Report on Low-Level Radioactive Waste Treatment, ORNL/TM-7427, Oak Ridge National Laboratory, Oak Ridge, Tennessee (September 1980).

5. J. E. Dieckhoner, "Sources, Production Rates and Characteristics of ERDA Low-Level Wastes," pp. 103-125 in Management of Low-Level Radioactive Wastes, Vol. 1, M. W. Carter, A. A. Moghissi and B. Kahn, editors, Pergamon Press, New York (1979).

6. National Research Council, The Shallow Land Burial of Low-Level Radioactively Contaminated Solid Waste, National Academy of Sciences, Washington, D. C. (1976).

7. J. W. Fenimore and R. L. Hooker, An Assessment of Solid Low-Level Waste Management at the Savannah River Plant, DPST-77-300, Savannah River Laboratory, Aiken, South Carolina (August 1977).

8. J. O. Duguid, Final Report on Assessment of DOE Low-Level Radioactive Solid Waste Disposal/Storage Activities, BMI-1984, Battelle Memorial Institute, Columbus, Ohio (November 1977).

9. USERDA, Final Environmental Statement, Waste Management Operations, Hanford Reservation, Richland, Washington, ERDA-1538 (December 1975).

10. USERDA, Final Environmental Statement, Waste Management Operations, Idaho Engineering Development Laboratory, ERDA-1536 (September 1977).

11. Gilbert/Commonwealth, Programmatic Assessment of Radioactive Waste Management, ORNL/Sub-80/13837/3, Reading, Pennsylvania (January 1980).

12. E. M. King, Oak Ridge National Laboratory, private communication (1981).

13. A. H. Kibbey, H. W. Godbee and E. L. Compere, A Review of Solid Radioactive Waste Practices in Light-Water-Cooled Nuclear Reactor Power Plants, NUREG/CR-0144, ORNL/NUREG-43, Oak Ridge National Laboratory, Oak Ridge, Tennessee (October 1978).

14. J. Phillips, F. Feizollahi, R. Martineit, W. Bell and R. Stouky, A Waste Inventory Report for Reactors and Fuel-Fabrication Facility Wastes, ONWI-20, NUS-3314, NUS Corporation, Rockville, Maryland (March 1979).

15. T. E. Quaka, Dresden Station Liquid Radwaste System Modifications, paper presented at ASME-IEEE Joint Power Generation Conference, Portland, Oregon, September 28 - October 1, 1975.

16. M. E. Martin and L. J. Riales, "Tennessee Valley Authority's Low-Level Radioactive Waste Management and Associated Environmental Impacts," pp. 569-579 in The State of Waste Isolation in the U.S. and Elsewhere, Advocacy Programs and Public Communications, Vol. 2, Proc. of ANS Topical Meeting, Waste Management '81, Tucson, Arizona, February 23-26, 1981, Roy G. Post, editor (1981).

17. B. A. Benda, "Non-Fuel Cycle Waste," pp. 621-628 in The State of Waste Disposal Technology and the Social and Political Implications, Proc. of Symposium on Waste Management '79, Tucson, Arizona, February 26 - March 1, 1979, Roy G. Post, editor (1979).

18. R. S. Yalow, "Disposal of Low-Level Radioactive Biomedical Wastes: A Problem in Regulation, Not Science," Radioactive Waste Management, Vol. 1(4), pp. 319-323 (May 1981).

19. E. Havlik, H. Bergmann and R. Hofer, "Problems of Disposal of Radioactive Wastes at a Nuclear-Clinical Medical Division," Radiobiologia Radiotherapia, Vol. 19(6), pp. 803-809 (1978), translated from the German by R. G. Mansfield, Office of Language Services, Oak Ridge National Laboratory, ORNL-tr-4697.

20. W. H. Briner, Special Problems of Medical Facilities, paper presented at Executive Conference; State, Federal, Nuclear Interface, American Nuclear Society, held in Monterey, California, February 1-4, 1981.

21. L. R. Cooley, M. R. McCampbell and J. D. Thompson, Current Practice of Incineration of Low-Level Institutional Radioactive Waste, EGG-2076, University of Maryland, Baltimore, Maryland (February 1981).

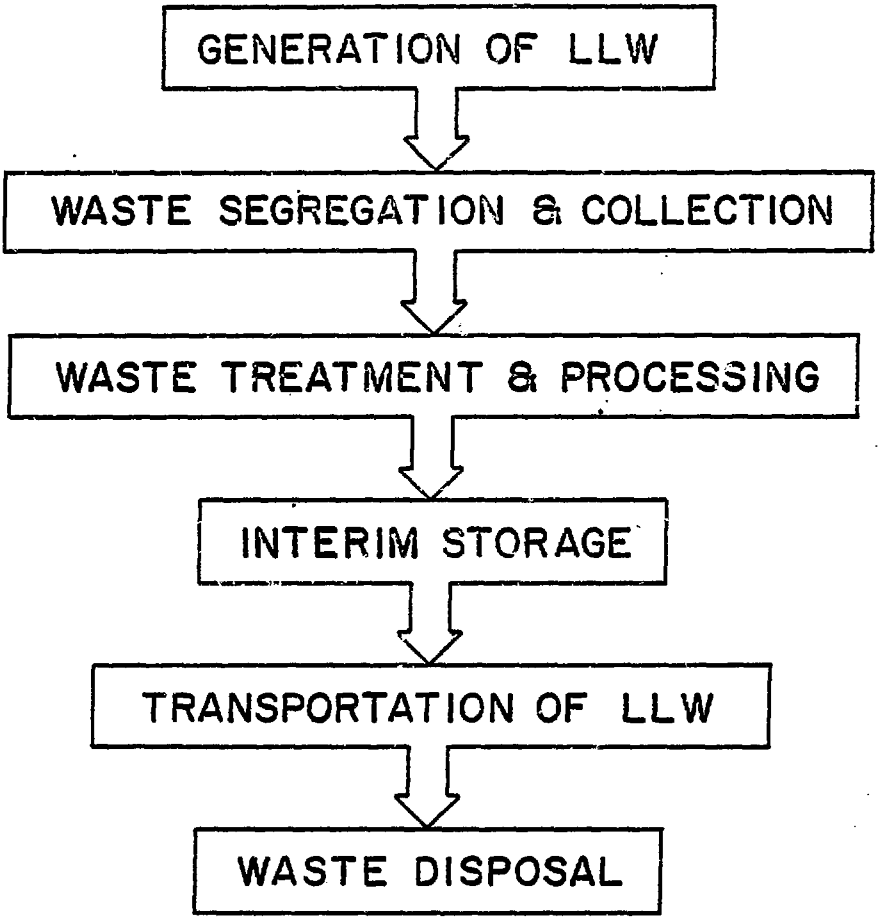

FIGURE 1. Management of Low-Level Waste (LLW).