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Low-Level Radioactive Waste from Commercial Nuclear Reactors

Volume 1. Recommendations for Technology Developments with Potential to Significantly Improve Low-Level Radioactive Waste Management

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Chemical Technology Division

LOW-LEVEL RADIOACTIVE WASTE FROM COMMERCIAL NUCLEAR REACTORS*

VOLUME 1. RECOMMENDATIONS FOR TECHNOLOGY DEVELOPMENTS WITH POTENTIAL TO SIGNIFICANTLY IMPROVE LOW-LEVEL RADIOACTIVE WASTE MANAGEMENT

(Activity KD 01 00 00 0, 00001)

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PREFACE AND ACKNOWLEDGMENTS

Volume 1 of this Low-Level Radioactive Waste (LLRW) Treatment Assessment series includes an executive summary, an introduction to the four-volume set, and a concise statement of research and development needs as determined by a literature review, interviews and correspondence with nuclear reactor operators, vendors, and key research personnel, and a workshop. Volume 2 reviews waste forms and sources, regulatory constraints, treatment technologies, packaging, transportation, and disposal alternatives. Volume 3 presents a collated collection of abstracts from most of the papers and reference documents used in this study. Volume 4 is the edited proceedings from the Workshop on Research and Development Needs for Treatment of Low-Level Radioactive Waste from Commercial Nuclear Reactors, which was held at Arlington, Virginia, on August 19-21, 1985.

This endeavor is the result of the collective effort of many individuals. The technical advice and suggestions of H. W. Godbee, A. H. Kibbey, and T. H. Row were invaluable. We appreciate the information supplied by the respondents to our survey of nuclear power plant operators, as well as the information from correspondence and interviews with the many engineers, scientists, and businesses active in waste treatment and disposal. R. A. Shaw, Electric Power Research Institute, E. A. Jennrich, Idaho National Engineering Laboratory, and D. L. Michlink, Tennessee Valley Authority, were especially helpful. We thank L. C. Oyen and R. F. Tucker, Jr., and their co-workers, of Sargent & Lundy Engineers, for compiling and critically evaluating the federal, state, and local regulatory constraints impacting on waste treatment, packaging, transportation, and disposal. Gratitude is also expressed to M. K. Bowers for her contributions to the compilation of the bibliographic abstracts from the literature.

We appreciate the input to this report provided by the speakers, panel members, and participants of the Workshop on Low-Level Radioactive Waste. We also wish to thank the following individuals for assistance in planning and conducting the LLRW Workshop: R. G. Rader, U.S. Department of Energy; R. Kohout, Ontario Hydro; T. S. LaGuardia, TLG Engineering, Inc.; R. M. Neilson, EG&G Idaho, Inc.; R. G. Post, University of Arizona; M. M. Thomas, Black and Veatch; and S. D. Clinton, E. J. Frederick, T. M. Gilliam, H. W. Godbee, A. H. Kibbey, and S. M. Robinson, all of Oak Ridge National Laboratory (ORNL). The workshop was coordinated by N. F. Cardwell and E. J. Frederick with the assistance of D. S. Brown, M. M. Dawson, and M. K. Bowers.

Thanks are especially due D. S. Brown and M. M. Dawson for preparing the final draft of the four volumes and to T. L. Bruner, A. R. Calhoun, M. A. Neal, J. T. Shannon, and D. R. Snow for typing assistance. Technical editing was capably accomplished by L. H. Bell, D. R. Reichle, F. M. Scheitlin, C. H. Shappert, and M. G. Stewart.

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ABSTRACT

The overall task of this program was to provide an assessment of currently available technology for treating commercial low-level radioactive waste (LLRW), to initiate development of a methodology for choosing one technology for a given application, and to identify research needed to improve current treatment techniques and decision methodology. The resulting report is issued in four volumes.

Volume 1 provides an executive summary and a general introduction to the four-volume set, in addition to recommendations for research and development (R&D) for low-level radioactive waste (LLRW) treatment. Generic, long-range, and/or high-risk programs identified and prioritized as needed R&D in the LLRW field include:

1. systems analysis to develop decision methodology;
2. alternative processes for dismantling, decontaminating, and decommissioning;
3. ion exchange;
4. incinerator technology;
5. disposal technology;
6. demonstration of advanced technologies;
7. technical assistance;
8. below regulatory concern materials;
9. mechanical treatment techniques;
10. monitoring and analysis procedures;
11. radical process improvements;
12. physical, chemical, thermal, and biological processes;
13. fundamental chemistry;
14. interim storage;
15. modeling; and
16. information transfer.

The several areas are discussed in detail.

EXECUTIVE SUMMARY

This low-level radioactive waste (LLRW) assessment placed emphasis on obtaining input from a broad spectrum of active participants in the field. Direct contacts were made with operating reactors, vendors, major programs, and government agencies. A survey was made of operating nuclear reactors to obtain information on the nature of their waste streams, present treatment methods, and research and development (R&D) needs. Questionnaires were returned from 56 of the 76 operating or nearly completed reactors (74% return). Vendors to the commercial LLRW generators were also surveyed. The principal commercial LLRW program work in the United States is conducted by the Electric Power Research Institute (EPRI), and this assessment benefited from our access to EPRI's data bases and reports.

A Workshop on Low-Level Radioactive Waste was held in Arlington, Virginia, on August 20–21, 1985. The Workshop was designed to be a concentrated study of LLRW R&D needs. Participants were carefully selected to give a balanced representation of the various aspects of LLRW management. Proceedings of the Workshop are published as Volume 4 of this report. Information generated by the Workshop is used throughout.

The two primary purposes of this assessment program for the Department of Energy (DOE) are to identify needed R&D in the commercial LLRW area and to provide an information matrix on technologies applicable to the treatment, storage, disposal, and transportation of the various LLRW types. Volume 1 presents a detailed discussion of R&D needs, and a brief prioritized list of these needs is given in this Executive Summary. Volume 2 provides extensive background information on treatment, storage disposal, and transportation (TSDT) technologies for reference by DOE and the commercial nuclear industry. A matrix of the treatment technologies applicable to various LLRW streams is also included in Volume 2. Volume 3 is an extensive compilation of abstracts relating to all major activity areas in the LLRW field (Part 1) and of the many regulatory constraints governing these areas (Part 2). Finally, Volume 4 includes Proceedings and major results of the LLRW Workshop.

Even though this assessment was mainly concerned with technology applications, the social, political, and regulatory issues that affect waste treatment technologies are briefly discussed.

Research and development priorities differ among the LLRW generators, disposal site operators, the public, politicians, regulators, or other federal agencies. Our prioritization of the commercial LLRW R&D needs identified in this assessment was done primarily from the federal viewpoint. Further, the basis of this viewpoint is the assumption that R&D is not to be considered a federal priority if it is simple, short-term, low-technology, nongeneric work that can be handled by the generators, vendors, or other LLRW management sectors. Thus, the identified research priorities are long-range, high-technology (or high-risk), generic research projects that will not or cannot be done easily by the nuclear industry.

Using these criteria, many R&D needs identified during the assessment were eliminated from our final listing. The eliminated items are considered those most suitable for funding by industry participants.

Examples of these include improvements in mechanical processes such as sorting, baling, sizing, segregation, cutting, sawing; application of available compaction/supercompaction systems; research on volume reduction improvements through changes in operating procedures, production and handling techniques, and staff education; and increased efficiency of operation, monitoring, and analytical techniques.

The generic, long-range, and/or high-risk programs identified by peers as needed R&D in the LLRW field during this assessment are listed here. These have been prioritized to reflect what is believed to be the ensuing degree of benefit to the nuclear industry.

1. <u>Systems analysis to develop decision methodology</u>

   Process improvements through systems analysis have a significant potential for important benefits in improving waste management efficiency. Generally, the waste management processes are considered separately rather than as integrated systems. Integration of these technologies would result in more efficient, safer, and more cost-effective waste management systems. In particular, the development of decision methodologies using advanced computer techniques will give the process operators more reliable ways of selecting technology applications to solve LLRW problems most efficiently. The indecision that now characterizes choice of technology applications could be largely relieved by development of a program (or programs) which would select the "best technology" based on operator inputs of the unique characteristics relating to the problem area.

2. Alternative processes for dismantling, decontaminating and decommissioning

Simpler processes that produce fewer undesirable side-products are needed. This area was identified as being particularly urgent during the assessment because of the planned obsolescence of numerous nuclear facilities. Much information is needed concerning available technologies and the new types of LLRW materials that will be produced in large quantities in the near future. First, a study is needed to predict the scope of dismantling/decommissioning activities for the entire nuclear industry, to avoid possibly unpleasant surprises and technology shortfalls. Then a concerted effort is needed to improve the available technologies and to develop new ones in time to meet projected needs. This long-term effort would forecast the types of LLRW materials to be dismantled, treated, and transported for disposal; it would also identify dismantling logistics and necessary technologies. For example, we know that readily disposable solvents are needed, as well as better methods for recycling, stabilizing, and disposing of the decontamination by-products.

After the types of LLRW to be handled have been identified and the required technologies have been defined, R&D efforts are needed to develop and demonstrate the new technologies. This is the type of long-range effort that industry generally is reluctant to carry out, and, because of this, there could be a significant federal role in this area.

3. Ion exchange

This is the most widely used of the physical, chemical, thermal, and biological (PCTB) processes in current use by the LLRW generators. Areas where research and development is needed are: (a) pretreatment of liquid waste streams, that is, more control of the contaminants introduced in the feed water; (b) improvement of the ion exchange resins, that is, higher-capacity materials; (c) development of split-stream processing concepts; (d) improved capacity for mixed wastes containing hazardous chemicals; (e) regeneration, which may create more waste volume but may also simplify ultimate resin disposal; (f) solidification of ion exchange materials for final disposal; (g) disposal options such as co-containerization with filter cartridges, etc.; and (h) methods for reducing the volume of the spent resins (e.g., microwave heating).

4. Incinerator technology

This was identified as the most widely considered new application in the technology survey. Some federal research assistance in this area could prevent the misapplication of inferior technology and result in considerable savings of time and money. The cost-effectiveness of various options for standard incinerator designs needs to be determined (e.g., fluidized-bed, liquid-injection, rotary kiln, controlled-air). Cost comparison studies are needed for small units at a single generator site vs multiple units at a central location. Regional siting under the Compact system needs to be compared to location at the disposal facility.

The economic effects of various incinerator designs and their acceptability to generators, regulators, and the general public need to be determined. The waste materials for which incineration is currently infeasible and the development of methods for processing and separating these materials should be candidates for federal R&D. Various off-gas treatment systems for incinerators, particularly the LLRW scrub solutions, need research and improvement. Maintenance procedures are needed that will ensure safe radiation levels to personnel. Methods for simplifying the entire incineration process will be necessary for widespread economic application of the technology. Methods are also needed for examining the ash resulting from incineration of LLRW to determine the methods of fixation required for disposal.

After these important design considerations have been determined, a prototype "package" unit for utility LLRW could be designed from the newly developed standards, to lower the cost and simplify incinerator operation. Other prototype incinerator units could be built for industrial and institutional LLRW generators (medical, biological, and other types of research).

5. Disposal technology

Because of the impending need to establish a number of new disposal sites (due to the Compact legislation), R&D in this area is urgently needed. It is generally agreed that new disposal sites should be significantly different from existing sites, and the technology is not presently available to properly design the new sites. For instance, LLRW wastes from decommissioning and decontamination are largely unidentified. Also, the effect of the increased concentration of radioactive species due to volume reduction at the burial sites is considered a major problem. Past difficulties with site integrity due to instability have increased public doubts about the ability to solve these problems with future sites.

The interaction and transport of waste forms in the final disposal environment are important areas for research. Because knowledge is lacking on species interaction and transport, both technologists and the public have often been surprised at the movement of such materials. One of the major unknown areas involves the effects of water on long-term waste form stability. A scientific basis is needed for deciding how much water is appropriate for optimum long-term disposal site performance.

Other questions concerning LLRW disposal that need to be addressed by the R&D community are the following: (1) How do burial sites behave when filled with waste forms? (2) What are some efficient mechanisms for collecting, analyzing, and treating water that has been in contact with the buried waste forms? (3) How can we extend the lifetimes of the burial sites that are already in operation? (4) What are the effects of decontamination/decommissioning wastes on the stability of waste forms and on burial-ground mobility of these materials? How do we predict future needs in this area? (5) How do we obtain better determinations of radionuclide concentrations in waste to ensure proper handling and disposal? (6) How do we resolve the current controversy among disposal site operators, utilities, states, and the public on volume reduction consequences and economics? (7) How do we ensure site stability for the long term?

6. Demonstration of advanced technologies

Certain federal agencies (e.g., DOE, EPA) are uniquely qualified to assist LLRW generators in a very significant way by using their wide range of expertise at high-technology facilities to provide large-scale demonstrations of complex new methods and processes. While the LLRW generators are reluctant to adopt "unproven high technology," they would welcome technologies that have been proven on a large scale. It is recommended that the federal programs create a formal liaison with EPRI, and perhaps others, to assure that advantages of an LLRW technology demonstration program will accrue to the commercial LLRW generators.

7. Technical assistance

Institutional and industrial generators of LLRW need technical assistance to offset the effects of constantly changing requirements from public, political, and regulatory sources.

8. Below regulatory concern materials

This area is viewed by the nuclear generators as having a potential for significant reduction of the total waste problem. It is believed that as much as 33% of certain categories of waste (such as low-specific-activity and many of the dry, active wastes) could be disposed of by less costly methods if "below regulatory concern" were properly defined. To accomplish this, R&D is needed in some areas. For example, development of more sensitive instruments for measuring very low radiation levels would give confidence that the material would not cause future problems when disposed of at a site not regulated for LLRW. New methods are needed for separating from LLRW the classes of material that could be proven to be no more hazardous than material now stored in sanitary landfills. Public confidence would be improved if a separate classification for this material could be established to ensure special handling at the sanitary landfills.

Technical assistance to the commercial sector is needed to establish 2 nCi/g as the standard "de minimis" radiation level. The Department of Transportation now uses this value in its regulation 49 CFR 170-189, and this value has been incorporated into the Nuclear Regulatory Commission's 10 CFR 71, by reference.

9. Mechanical treatment techniques

These are widely applied technologies in the commercial nuclear industry because of their simplicity and low capital costs. There are a number of mechanical treatment areas where the LLRW generators could benefit from advanced R&D programs.

Baling is not widely used but, with proper design, could make a significant contribution. Simple baling should be left to vendors to develop, but development by DOE of a system to accomplish both compaction and package preparation during baling would give important flexibility to produce final forms that optimize space allocations.

Supercompaction may have a very beneficial effect in decreasing the mobility of radionuclides and other chemical constituents in disposal by land burial. Methods of improving this utility, such as placing certain materials in special packaging materials before supercompaction, need to be explored.

Remote handling/robotics technologies for use in radiation work areas are needed. An effort to develop these, along with an assessment of their dose-reduction potential, needs to be instituted.

The best approach would be a continuous long-term effort rather than short-term emphasis on only one or two technologies. Emphasis would best be placed on generic developments that can be integrated into commercially produced devices. An effort of this kind would support not only the LLRW generators but also the equipment manufacturers, providing generic R&D they cannot afford or will not do for various reasons.

10. Monitoring and analysis procedures

Present technology in these areas is inadequate. More automation of waste monitoring is needed, as well as better methods for low-level radiation detection, particularly for measurements through various container materials. Species analyses of radioactive materials, especially of mixtures or complicated materials, need improvement. The most critical need is for chemical species analyses on all the Resource Conservation and Recovery Act (RCRA) materials that are mixed with the LLRW.

11. Radical process improvements

Significant process improvements are needed, for example, in the operation of purification equipment. Also, the development of radionuclide-specific concentration methods could produce a "clean" stream suitable for recycling and a much smaller volume of material for further treatment or disposal.

Processes that produce mixed wastes require detailed study to find and evaluate reasonable alternatives that will decrease the output of this type of undesirable material. Alternatives may be found in direct substitution, recycling of certain problem materials, or regeneration and reuse of selected materials. Specific types of materials to be eliminated, if possible, include polyvinyl chlorides (PVCs), chemical solvents, and chelating solutions. An example of a promising technology that needs R&D support is the use of microwave energy to destroy PVC waste materials.

12. Physical, chemical, thermal, and biological (PCTB) processes

These processes are underutilized in LLRW management, and a thorough study is needed to identify ways that the PCTB processes can be effectively used. While the LLRW waste generators are hesitant to do this work because of the complexity and the expense involved, potential savings are too great to ignore this important area.

After applicability studies to identify the most promising technologies, an R&D program needs to be instituted to develop the best applications to fit the LLRW generator situations. For example, the use of acid digestion for processing spent ion exchange resins could be investigated further. Another process that has not been explored in the United States is the treatment of resins with hydrogen peroxide to produce liquid waste forms that can then be reduced in volume by evaporation before resolidification. The Canadian work with pyrohydrolysis could also be monitored for possible application in this country.

13. Fundamental chemistry

The basic chemistry of the various liquid LLRW streams is poorly understood. This lack of accurate information has resulted in misapplication of existing technology, poor long-term process performance, and higher waste management costs. Also, research on the fundamental chemistry of final waste forms is needed to support waste burial site regulators and operators in either developing appropriate restrictions or enforcing the existing requirements. Disposal policy for ion exchange resins is a specific area where fundamental chemistry research could make a significant difference.

14. Interim storage

Storage of wastes at LLRW generator sites will likely become necessary due to impending amendments to the LLRW Policy Act. These amendments are projected to increase the time frame for establishing burial sites in the Compact regions; thus, limitations on storage volume at the three sites presently in operation would force interim storage.

For short-term storage, the R&D needs are: monitoring of stored material (particularly resins), radiolytic gas generation, radiation-enhanced degradation of polymeric materials, corrosion, and disposal behavior of materials that have been stored.

For long-term storage, the R&D needs (in addition to those listed above) are: effects of temperature and humidity on properties of cement waste forms, gas generation by biodegradation, long-term maintenance problems, space, costs, and public opposition.

15. Modeling

Most modeling codes for LLRW waste management are one-dimensional, poorly developed, and have little or no verification with actual data.

Modeling input needs that were identified include: better hydrogeological data (e.g., delineation of the water tables, flow patterns of underground aquifers, interaction of waste materials with water); accurate species-tracking information (e.g., identification of naturally occurring ligands that can increase transfer rates up to 1000 times, retention characteristics of soil); standardization; and information on-site leakage factors.

Code development needs include: sensitivity analyses (should be given priority); modeling over the full range of conception, development, calibration, and validation; and three-dimensional transport codes (these have been needed for 10 years but have not had R&D support).

Modeling codes developed for LLRW need validation using data from actual operating systems or demonstration-scale operations.

16. Information transfer

This is included in our listing since there is an urgent need for improved sharing of R&D information. Federal research, in particular, was characterized by the commercial sector as "hidden in government reports." A federal journal patterned after the very succesful EPRI Journal would facilitate technology transfer in the LLRW area. A federal reports abstract distribution service to those who have previously indicated a need to know could provide important information on particular subject areas. There is a special need for information exchange on solidifying agents and for continuing and improved LLRW surveys, which are very useful to the Compacts during this formative period.

1. INTRODUCTION

Nuclear power plants in the United States generate large quantities of dry compactible and noncompactible solids, liquids, and sludges that contain low-level radioactive wastes (LLRW). Other LLRW generators, such as institutions and industries, produce wastes that vary in nature and that often contain mixtures of hazardous chemicals with the radioactive wastes. At present, all LLRW materials must be disposed of in only three sites, and two have limits on both the volume and radioactive content that they will accept. The states are now forming regional Compact systems, which no doubt will develop further requirements. In this climate, the waste generators are seeking the most cost-competitive combinations of treatment, storage, transportation, and disposal systems to fit these changing criteria. Quite often the information necessary to correct waste management decisions is either missing or unavailable within the needed time frame.

In response to a number of recent forcing factors, such as the LLRW Policy Act of 1980 (PL 96-573 1980), the acceptance limits imposed by the disposal sites, and the Environmental Protection Agency's (EPA's) entrance in the mixed-waste disposal area, large LLRW generators have installed new capacity to treat LLRW materials. Their approach generally has been cautious and conservative, and simple techniques such as compaction and sorting have dominated their efforts. At the outset, most generators believed these simple procedures would be sufficient. However, more recently this simplistic approach is being questioned. It has become evident that better applications and more advanced technologies would give significant increases in efficiencies, greater flexibility in meeting the constantly changing demands, and overall improvements in cost-effectiveness of LLRW management.

The DOE is familiar with all aspects of this problem and funded this assessment primarily to answer the question: Is further research and development (R&D) needed? If so, what are the R&D needs, and what should the priorities be? Since DOE also recognized the need for assistance to LLRW generators in selecting and applying appropriate existing waste management technologies, another aspect of this assignment was the production of a matrix of technologies to assist the generators in selecting the best available technologies for use on particular waste streams. The approach suggested by the DOE to accomplish these goals was to place major emphasis on obtaining input by direct contacts with waste generators and others in the LLRW management field, by attending the important conferences on LLRW management, and by sponsoring a workshop with attendees representing all areas of the field. Such an approach should give the proper balance to the conclusions of this assessment.

This project began in November 1984. In June 1985, nuclear reactor operators were surveyed concerning LLRW treatment methods presently used, discontinued, or under consideration for future uses. A Workshop on LLRW Management needs was held in the Washington area in August 1985. The summary report was first issued in draft form in September 1985. The report consists of four volumes. Volume 1 includes the R&D recommendations; Volume 2 summarizes details of the treatment, storage, disposal, and transportation technologies, and presents the matrix of treatment technologies vs waste streams. Volume 3 contains bibliographic abstracts of the significant source references (Part 1); Part 2 contains treatment, storage, disposal, and transportation constraints. Volume 4 gives the Workshop Proceedings.

After a thorough analysis, it was concluded that there is a need to support the commercial industries that generate LLRW. This support should include:

1. technical assistance,
2. research and development, and
3. technology demonstration.

1.1 TECHNICAL ASSISTANCE NEEDS

To say that these are difficult times for generators of LLRW is an understatement. The quantities of waste generated are large* (EPRI 1984a), and there are only two widely separated sites which are

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*Using EPRI's 1981 estimate of the average waste generation rate for BWRs and PWRs, the LLRW volume for reactors operating in 1985 is 91,600 m^3/year. The total LLRW shipped in 1981 (according to NRC records) was 83,726 m^3. The 1985 LLRW volume estimate for currently operating and under-construction reactors is 138,500 m^3 (i.e., if all were currently on-line, the waste generated would be near this amount).

licensed to accept commercial LLRW: Barnwell, South Carolina, and Richland, Washington. (There is a third site at Beatty, Nevada, which currently accepts very little commercial waste.) These sites are under pressure to limit the amount of waste accepted and, thus, impose quantity-per-unit-time limits on the material received for disposal. The LLRW Policy Act of 1980 has started in motion the formation of regional Compacts, each with its own disposal sites. However, the targets set by that Act are not being met and there is a rush to approve amended legislation which considerably extends the time and scope of the original Act (HR 1083 1985). The involvement of the states has increased the public focus on the issue. It is more difficult to license a site, especially since the Environmental Protection Agency (EPA) has decided that LLRW sites which accept mixed radioactive/chemical wastes must be licensed under the Resource Conservation and Recovery Act (RCRA) by November 1985 (J. J. Scoville, U.S. Ecology, LLWMP 1985).

Large generators, such as utilities with nuclear power generating stations, are heavily involved with waste volume reduction (VR) due to the disposal quantity limitations and the increasing costs of LLRW handling and disposal. The utilities must consider long-term storage on-site because of conflicting legislation and the uncertainty of disposal sites. Technical advice and assistance are needed in choosing appropriate waste treatment equipment that will be both cost-effective and environmentally acceptable. Some waste generators may have difficulty deciding which incinerator, evaporator, liquid-liquid extractor, or other option to use when confronted with several feasible process choices. To date, such technical assistance has been provided for the nuclear power industry mainly by the Electric Power Research Institute (EPRI 1980).

Even though most large LLRW generators would welcome help from the DOE, the industrial and institutional waste generators are also in need of assistance. In many ways their needs are more acute, because they generally have fewer resources and a larger percentage of their LLRW has both radioactive and chemically hazardous components. These mixed wastes are not clearly defined or regulated at present, but, as mentioned previously, the EPA has stated that LLRW sites accepting these mixed wastes after November 1985 must be licensed under the RCRA. A representative of one of the disposal site operators (A. Crase, U.S. Ecology, ORNL 1985) has subsequently stated that his company will file a site-closure plan rather than an application for an RCRA permit for mixed wastes, because of the difficulty of complying with EPA's Part B licensing requirements within the given time frame. It would not be surprising if the remaining LLRW disposal site operator follows suit. The small LLRW generators will be faced with a particularly difficult situation, since their limited resources will not permit them to handle a long-term waste accumulation. Obviously, they need both advice and assistance. Regardless of the outcome of the current impasse on the disposal of mixed wastes, it seems assured that additional restrictions will be imposed on all LLRW generators in the next few years.

1.2 RESEARCH AND DEVELOPMENT

1.2.1 Is There Need for Further R&D in the LLRW Field?

There is currently a faction holding the view that there is no further need for R&D in the LLRW area. At a recent meeting, a DOE official (LLWMP 1985) was quoted as saying:

- Waste treatment techniques are available and cost-effective;
- Corrective measures are known and adequate; and
- The foundation for waste treatment models is adequate.

Yet, when the reactor operators were surveyed (see Volume 2 of this report) they listed numerous problem areas and indicated that much R&D was needed. These LLRW survey results are briefly summarized here (no priority intended).

Specific problem areas identified in LLRW treatment include:

1. decontamination systems;
2. in-plant solidification systems;
3. exposure when using solidification;
4. evaporators;
5. handling and disposal of contaminated oily wastes;
6. stabilization of oil and oily material;
7. handling and disposal of wet sludge;
8. handling and disposal of contaminated organic solvents;
9. filter operation;
10. traveling belt filters in radwaste systems;

11. filter disposal methods, especially liquid stream filters;
12. handling and disposal of low-level resin;
13. sampling (e.g., spent resins);
14. solidification of bead resin (10 CFR 61);
15. resin activity measurement;
16. removing contaminated sand and rubble from the system;
17. cobalt and cesium removal from resins;
18. handling and disposal of mercury;
19. stability requirements of 10 CFR 61;
20. burial of waste in 1986 and beyond;
21. overall volume reduction;
22. waste collection tanks;
23. handling and disposal of liquid scintillation fluids; and
24. type and quantity of storage space needed.

In addition, survey respondents made specific R&D recommendations for the development of methods for:

1. chemical decontamination of the full reactor cooling system;
2. destroying chelates;
3. reducing and/or removing radionuclides before disposal (e.g., ^{14}C);
4. gamma-scanning of spent-resin storage tanks to determine whether solidification is necessary;
5. treatment of sludge from waste collection tanks;
6. efficient low-cost incineration;
7. efficient low-cost decontamination with minimal residues;
8. removal of fines from liquid waste systems;
9. regeneration of bead resin to ~100% ion exchange capacity;
10. developing resins with greater capacity;
11. treating and disposing of oily wastes;
12. treating mercury for recovery or disposal;
13. treating scintillation materials for disposal;
14. analyzing non-LSA (low-specific-activity) materials;
15. packaging mechanical filter cartridges that exceed radiation of waste class "C" (>100 nCi TRU/g);
16. efficient drying;
17. developing mobile incineration services;

18. determining "de minimis" levels for release of oil, rubble, sand, low-level resin, radionuclides and other materials;
19. TRU low-level analysis;
20. waste stream analysis (10 CFR 61);
21. treating wet sludge;
22. reliable uncomplicated in-plant solidification systems with low maintenance; and
23. economically feasible VR technologies, including methods applicable to resins.

Although most of the needs listed above pertain to the treatment and processing of LLRW, R&D focused on the ultimate disposal of LLRW was also identified as an urgent need by this investigation.

For example, EPRI has not, in the past, emphasized the development of LLRW disposal technology; however, they now agree that nuclear power generators need information on current developments in this area such as Compacts, new legislation, new standards, and effects of these on current disposal technologies. An EPRI spokesman (R. A. Shaw, EPRI, LWMP 1985) who once believed "all that we needed was ammunition for utilities to go to the states to convince them that shallow land burial was adequate," has recently stated that "We will not be able to live with shallow land burial in the future . . . as technologists we had better get moving."

Shaw's position is that shallow-land burial (SLB) is adequate and all that is needed, but the increasing dominance of sociopolitical pressures will force the development of more acceptable alternatives. This means R&D is needed to design engineered features with guarantees of performance acceptable to the public.

Another EPRI representative (S. A. Hobart, EPRI, ORNL 1985) has identified other disposal concerns:

> The requirements of the new compact burial sites are completely unknown. Since state politicians will be involved, it is likely they will be more stringent. In what ways? What kinds of paperwork will be required? What waste forms? What advanced notice of in-transit tracking? How can we prepare now when we do not know for what to prepare? New federal regulatory concerns have arisen. It could be argued that we caused those as a result of putting more radioactivity in each container. So

> now, how do we best identify the isotopes in that waste? Are scaling factors the answer? Are they in the best interest of either the utility or the public? How do we monitor and predict hydrogen generated from radiolytic degradation of organic materials, such as resins? More seriously, how do we make that waste form stable at the burial site over the long term?

It is evident from our assessment that there is a definite need for R&D in the treatment and disposal of LLRW.

1.2.2 What Treatment R&D is Needed?

To answer this question, it is important to include input from experts in the field. Expressly for this purpose, a Workshop on LLRW Management was held in Arlington, Virginia, on August 20–21, 1985 (ORNL 1985). Attendees were invited from all fields complementary to LLRW management, and results of that Workshop are presented in detail in Volume 4 of this report. Thomas and Kibbey (ORNL 1985) have summarized conclusions of the Workshop with the following remarks:

> While some participants maintained that the required processing technology was in place and that LLRW problems are a purely sociopolitical problem, the majority agreed that there are significant data gaps and there is a definite need to put LLRW processing on a firmer scientific basis. At the same time, we believe all would agree that the problems are most definitely solvable with a straightforward commitment of the appropriate resources. The biggest need is for the industry to seize the initiative and abandon its current reactive posture.

The LLRW R&D needs, as determined by those attending the Workshop and other peers in the field, are discussed by topic in the following sections.

1.2.2.1 Sorting/Segregation and Decontamination

Automatic Detection and Separation

The most important needs identified in sorting/segregation are for

1. reliable instrumentation to accurately detect radiation at very low levels, and
2. a method of separating LLRW from nonradioactive material.

Most of the present instrumentation cannot detect low levels of radiation to "de minimis" levels. Many of the hand-operated devices used are unsuitable for automation. Special sorting and segregation instrumentation and automated separation equipment will be needed to detect

RCRA wastes and segregate them from radioactive materials and other material that can be disposed of in a municipal landfill. Processes will have to be developed to treat the mixed wastes that cannot be separated.

Decontamination

Decontamination almost never meets desired performance criteria and often produces large amounts of hazardous secondary materials. Alternative processes for decontamination are needed which are simpler and produce less of the undesirable side-products. Readily disposable solvents, better recycling methods, and better methods of stabilizing and disposing of the byproducts of decontamination are needed. It may be undesirable to decontaminate a radioactive waste if this will generate larger quantities of a mixed waste regulated under RCRA. Since most decontamination methods are designed for highly radioactive materials, new processes need to be designed specifically for LLRW. Many of the undesirable byproducts arising from the more severe process applications may thus be eliminated. This area requires some serious action now, before many of the large-scale commercial nuclear reactors have to be decommissioned (EPRI 1985).

Packaging

After sorting, segregation, and/or decontamination, the LLRW materials must be efficiently packed into containers that preserve the resulting volume decrease. Research is needed to determine the best container types and shapes for packaging specific waste materials. There is also a need for research on methods for determining the life expectancy of LLRW containers. The useful life of storage containers is often determined after the fact because there is no accurate prediction method. Such research would also allow savings through designing future containers to better fit the usage; at present, a heavier container than is actually needed may be used "just to be safe." Improving the design of containers for longer-term storage requirements would also increase public confidence.

1.2.2.2 Liquid Streams

Purification of Waste Streams to Permit Recycling

An important area needing R&D is the purification of various waste streams to permit recycling. Four specific research areas should be addressed.

1. Radionuclide-specific concentration processes are needed to produce a "clean" stream suitable for recycling and a concentrated stream with far less material for disposal. There are significant concerns in the areas of quality control of materials, hydrogen generation, the applicability of this approach to streams having high economic value (such as reactor coolant), and its compatibility with current solidification media and long-term disposal criteria.
2. Analytical procedures and equipment are needed to enable rapid accurate measurement of trace contaminants in process and waste streams. These would be of economic benefit by allowing waste generators to determine when a stream needs to be treated and when it is of suitable purity for recycle or discharge.
3. Effects of process improvements on the overall operation of purification equipment should be quantified. For instance, upstream unit operations that affect particle dispersion and ionic association will have a very large effect on the operation of hyperfilters and ion exchange media. There is a need to identify and quantify this synergism to improve total system performance and to reduce costs.
4. Fundamental chemistry of the various liquid streams should be investigated. The lack of accurate chemical information has resulted in misapplication of existing technology, poor long-term performance, and higher costs.

Removal of water for final waste disposal

The amount of water in final waste forms such as grouts, glasses, and polymers in sealed drums or high-integrity containers (HICs) must be closely controlled if the final product is to have the long-term stability required by regulators. Research is particularly needed in the following areas:

1. The effects of water on long-term waste stability are not well understood. What is needed is a scientific basis for deciding how much water is appropriate for optimum long-term performance. Information is needed, for example, concerning the effects of water on gas generation, integrity of the monolith, freeze-thaw resistance, and leachability performance. The freeze-thaw resistance will become even more important as the trend towards long-term aboveground storage develops.

2. The fundamental chemistry of final waste form development is needed to support waste burial site regulators and operators in developing appropriate restrictions and in best utilizing the existing requirements. In some cases there is considerable doubt whether the requirements are actually related to the disposal needs. The latter are often not known, and over-regulation is necessary to avoid embarrassing errors. Understanding the fundamental chemistry of the final waste form would allow regulators to dictate more reasonable requirements, the operators to design more cost-effective disposal sites, and the public to have more confidence in the whole process of LLRW disposal.

3. The policy on the disposal of ion exchange resin is an example of an area where fundamental chemistry research could make a significant difference. The present policy is not founded on accurate scientific data. Information is particularly needed in the following areas:
   (a) long-term stability or degradation of resins,
   (b) effects of water on biodegradation,
   (c) the necessity of high-efficiency dehydration of resins,
   (d) nondestructive verification procedures for determining the water content of packaged resins,
   (e) long-term compatibility of HIC materials with resins, and
   (f) a firm chemical data base to support the design of advanced resin drying systems and their integration with solidification systems.

4. Process improvements through systems analysis may result in important changes in waste management. Generally, the waste management processes are considered separately, not as parts of an integrated system. Integration of technology would help achieve the goal of more efficient and cost-effective waste management systems. To accomplish this, the following will be required:
   (a) development of a chemical and engineering basis for selecting appropriate technologies;
   (b) examination of existing technology for applicability and adaptability;
   (c) studies and tests needed to properly develop new equipment and procedures;

(d) definition of the desired end product (e.g., streams suitable for recycle, resource recovery, or direct discharge);

(e) products more acceptable for long-term storage or disposal; and

(f) cooperative development and sharing of information resources among the federal government, utilities, industrial and institutional LLRW generators, and equipment vendors.

1.2.2.3. Physical, Chemical, Thermal, and Biological Treatments

There is limited use of the large number of physical, chemical, thermal, and biological (PCTB) treatment technologies that are available. This is partially because, in the past, plenty of disposal space was available at reasonable prices. As burial space has become limited and more expensive the response has been to increase use of simple "low technology" fixes such as sorting and compacting. (The exception to this is the very recent interest in incineration, which is just developing in some areas.) Many promising PCTB technologies such as acid digestion, wet-air oxidation, vitrification, smelting, electrolytic processes, oxidation-reduction, and liquid-liquid extraction (Rodgers et al. 1985) have largely been ignored for handling of LLRW.

PCTB application studies

There is a need for a thorough study to identify areas where the PCTB processes can be effectively utilized in LLRW management. While the waste generators are skeptical of the additional complexity, expense, and capital expenditures necessary to implement new technologies, the potential savings are too great to ignore these new resources. After applicability studies identify the most promising technologies, an R&D program should be instituted to develop the best applications to fit the particular LLRW generator situations.

Ion exchange

Ion exchange is the most widely used of the PCTB processes currently employed by the LLRW generators. Research and development are needed on:

1. pretreatment of liquid waste streams (i.e., more control of the contaminants introduced in the feed water);
2. improvement of the ion exchange resins (i.e., higher-capacity materials);
3. development of split-stream processing concepts;

4. improvement of capacity for mixed wastes that contain hazardous chemicals;
5. regeneration of resins (regeneration may create more LLRW volume, but it may also simplify ultimate resin disposal);
6. solidification of ion exchange materials in preparation for final disposal;
7. disposal of HICs after dewatering (e.g., co-containerization with filter cartridges, etc.); and
8. development of methods for reducing the volume of the spent resins (e.g., microwave heating to reduce volume).

Digestion

The digestion process has been greatly simplified and can now be done remotely with no moving parts. A wide variety of waste streams can be handled including resins, combustible solids, sludges, and some hazardous chemicals. These applications should be explored in a feasibility study on acid digestion for LLRW. The economics have been defined for numerous applications, and usefulness of the process has been demonstrated satisfactorily for TRU wastes and some resins. Despite these positive aspects, no utility has invested in a digestion unit for treatment of an LLRW stream. An application that definitely needs R&D is the use of acid digestion for processing spent ion exchange resins. If the application proves to be feasible, perhaps a portable unit could be developed, with the acid digestion residue to be solidified in glass.

Incineration

Incineration is now being considered by a number of facilities because of its versatility and the very large volume reductions that can be achieved. However, because of a lack of substantive data for incineration, the conservative LLRW generators have been slow to adopt this promising technology. This is an area where some assistance by federal organizations, such as the DOE, could make an immediate impact. Research and development studies are needed to:

1. Determine the cost effectiveness of various options for standard incinerator designs and use patterns. Current options include: small incinerators for specific use at a generating site; incinerators for multiple use at a generating site; incinerators for

regional use (e.g., a Compact); incinerator located at disposal facilities.

2. Determine the waste materials for which incineration is applicable, with particular emphasis on its applicability for mixed wastes.
3. Examine methods of processing and separating waste streams within the generator scheme to produce feed for the incinerator.
4. Examine various off-gas treatment systems for LLRW incinerators, particularly for the resulting off-gas scrub solution.
5. Determine maintenance procedures that would ensure safe radiation levels for personnel. Also, look at methods for simplifying maintenance operations, perhaps through more automation and use of robotic, remote-controlled devices.
6. Examine means for fixing the resulting ash from incineration of LLRW for final disposal. This is one of the primary concerns when incineration of LLRW is considered. Satisfactory solution of this problem would result in much wider acceptance of the technology.
7. Conduct a research study to determine the type of incinerator best suited for use by major LLRW generators such as commercial utilities. After this determination, a "package" unit could be designed from developed standards that would lower costs and simplify incinerator operation for this particular application. Following this, the same types of studies could be done for other industrial and institutional LLRW generators.
8. Determine the feasibility of mobile LLRW incinerators operated by subcontractors. This option would relieve utilities of the operating duties as well as the capital investment. Also, operating and capital costs for incineration could probably be significantly lowered if the utilities invested in central incineration sites. A study to determine the best options is needed. One utility is currently experimenting with the mobile incinerator idea. Commonwealth Edison contracted with Aerojet (Aerojet 1979) to develop a mobile incinerator after they had determined that the use of mobile incinerators would lower capital investment costs (LLWMP 1985). The single incinerator can be moved to each facility as needed, rather than building smaller incinerators at

each plant and having them remain idle for considerable periods. Incinerator siting problems are also avoided.

Oxidation/Reduction

Applications of this technology are not readily apparent, but the potential is there. A project should be instituted to examine possible applications of oxidation/reduction. An initial candidate for investigation would be the treatment of resins with hydrogen peroxide to convert them to a liquid form that could then be reduced in volume by evaporation before resolidification.

1.2.2.4 Mechanical Treatment of LLRW

Volume Reduction

This mechanical treatment process has been the focal point for LLRW generators during the recent past (EPRI 1984b; USNRC 1981). In addition to internal savings, volume reduction results in a significant savings on disposal costs. Also, regulations now being formulated (e.g., amendments to the LLRW Policy Act of 1980 and the preliminary Compact regulations) are almost certain to require some volume reduction. Although the volume reductions achieved thus far have not been large, they have had some effect on the total LLRW volume needing disposal. This is reflected in the following remarks by burial-ground operator Arvin Crase, of U.S. Ecology (ORNL 1985), at the Workshop on LLRW management:

> The nation's waste volume peaked at approximately 4 million ft^3 a little over 3 years ago, and since that time it has decreased. Statistically, there is very little difference between the waste volume generated in '83 vs '84. We at U.S. Ecology believe that volume reduction and other techniques to reduce the amount of waste delivered to the burial sites is offsetting the growth (in new plants) . . . we see a real growth of about 3% a year.

Some other comments on volume reduction that were made at the Workshop include the following:

> We have been working toward volume reduction for 5 to 6 years, and we are making some gains in that area. To publicly say, as an industry, that we don't need volume reduction improvements is irresponsible (Joe Walden, Alabama Power Co., ORNL 1985).

> It seems to me that the two prime future R&D efforts in the next 5 to 10 years should be source elimination and analysis of disposal site economics (Gary Benda, Chem-Nuclear Systems, ORNL 1985).

Compacting, Sizing, Dismantlement, and Filtration

These are among the most-used mechanical treatment techniques of the LLRW generators because of their simplicity and low capital costs (EPRI 1980). However, LLRW generators generally take what the vendors offer rather than designing a system for their particular application. Often the vendor offerings are far from ideal. There are a number of mechanical treatment areas where the LLRW generators could benefit from R&D programs. These are discussed below.

Low-pressure in-drum compaction. This would be useful as a technique for generators who have little need for waste treatment. This method is simple and should be left to the vendors to develop, although some encouragement to the vendors to improve methods of in-drum compaction would be useful.

Baling. Baling is not widely used, but it could make a significant contribution to LLRW if properly designed. Baling should be designed to accomplish both compaction and package preparation. The material should be tightly compacted and then fitted to a package suitable for storing, transporting, or final disposal. One of the advantages to this procedure is the flexibility to produce final forms that optimize space allocations.

Supercompaction. This technique is developed to the point that theoretical densities are being approached. However, important gains can still be made by developing machines with the capability to produce geometric shapes that will better utilize the storage space by more efficient packing.

Another aspect of supercompaction that has not been fully explored is the possibility that the waste immobility achieved through supercompaction may have a beneficial effect on decreasing mobility of radionuclides and other chemical constituents in disposal by land burial. Methods for increasing the efficiency of this practice should be the subject of R&D studies.

Sizing. Large potential gains in efficiency of LLRW management may be possible through sizing. The object is to reduce waste volume by such methods as cutting, shearing, sawing, and shredding, which would allow more waste materials to be placed in a shipping container. A number of dedicated systems for mechanical volume reduction are currently being used, but the efficiency, in general, is not very high. The currently used techniques should be reviewed and assessed for possible improvements in efficiency, including tooling and remote control applications. Other, more advanced techniques (such as plasma-arc technology and hydrolasers) should be supported for further development since they are promising technologies for future use in decommissioning operations.

Dismantling/Decommissioning. Dismantling/decommissioning technologies are poorly developed at present because the number of applications has been small. This situation will change in the near future as the older nuclear power plants and other fuel-cycle facilities are decommissioned. In fact, during the Workshop on LLRW Management, this was identified as a potential future problem area. It is anticipated that both the technologies to be used and the LLRW materials generated by these activities will be significantly different from those of the present, and new approaches will be required. First, a study should be carried out to determine the extent of dismantling/decommissioning to be expected in the future. This effort should forecast the types of materials to be dismantled, treated, and transported for disposal. It should also identify dismantling logistics and the necessary associated technologies, both existing and needed. Next, a concerted, several-year effort should be initiated to improve the existing technologies and to develop and demonstrate new ones by the time they are needed.

This is a case where we can predict, due to planned nuclear plant obsolescence, that a significant future effort will be required if the decommissioning is to be done in a cost-effective manner. Since industry is reluctant to carry out this type of long-term R&D effort, a significant federal role will be needed. However, the time frame requires that this effort should not be delayed, if the information is to be made available when needed.

Remote handling technology. There is a need for simple, inexpensive, remote handling/robotic technologies for tasks in high-radiation work areas. A long-range effort to develop such technologies, with an assessment of the potential for dose reduction to plant operators, should be instituted in a long-range coordinated effort. Emphasis should be placed on developments of a generic nature that can be integrated into various devices to be manufactured by vendors. Because of the long-term, comprehensive nature of this project, it is a candidate for government funding. An effort of this kind supports not only the LLRW generators but also the equipment manufacturers, by providing generic R&D they cannot afford or will not do for various reasons.

Filtration. This is an old and accepted method of removing materials from contaminated streams. However, streams containing radioactive material present new problems that, for the most part, are still unsolved. For example, R&D is needed to determine the most suitable filter media for particular radioactive species; to develop methods for safely replacing the used (now radioactive) filters; to remove accumulated radioactive materials, and to determine factors affecting filter operators. Filtration methods could be made more efficient and more useful to LLRW generators if R&D could answer some of these questions.

1.2.2.5 Generic Developments Needed to Support All Waste Treatment Areas

Certain studies are needed to support all aspects of LLRW management. In this category, the ones most mentioned by participants in LLRW meetings during 1984–1985, and in the direct contacts made by the assessment staff, were modeling, monitoring and analysis, information transfer, sociopolitical issue resolution, and costing. In some cases, particular aspects of these were mentioned within the appropriate preceding sections. Other aspects of such studies will be discussed here.

Modeling

Modeling is accomplished in three stages. First, the inputs to the models are developed. These inputs are usually fundamental parameters describing the behavior of waste materials and often are generated by studies designed especially for models. Second, computer code developments are formulated to manipulate the input data and give useful output. Third, the outputs are verified by comparison with "real" data under identical circumstances.

Input needs identified are:

1. Better hydrogeological information. This includes improving the delineation of the water table, tracking flow patterns of underground aquifers, and determining interaction of waste materials with water.

2. Species-tracking information. Research is needed to identify naturally occuring ligands which can increase transfer rates up to 1000 times and to determine retention characteristics of soil.
3. Standardization of input format.
4. Information on site leakage factors.

Code development needs identified were:

1. sensitivity analyses (should be given priority);
2. modeling over the full range (i.e., conception, development, calibration, and validation); and
3. three-dimensional transport codes (have been needed for 10 years but have not been supported).

Validation needs were also identified. Real data must be developed specifically to validate new models. The data should be from real operating systems or from demonstration-scale operations.

Monitoring and Analysis

We need to learn how to monitor with minimum manpower through more automation. Chemical species analyses are needed for all the RCRA materials that are mixed with the radioactive materials. Better methods are needed for species analyses on radioactive materials, particularly when they are mixed with other complicated materials. Better methods of radiation detection are needed, especially for low levels and for detection through various types of containers.

Information Transfer

There is a serious need for the DOE, NRC, USGS, universities, Corps of Engineers, and others in this field to work together on a technical level. Since no single organization has the obvious leadership role in this, DOE or some other agency must assume that role. Information exchange is needed in several areas, such as solidifying agents.

We should also continue to improve LLRW surveys. They are particularly useful to the Compacts during this formative period. The DOE research, in particular, may be characterized as "hidden in government reports." Perhaps DOE should institute a LLRW journal, patterned after the successful journal produced by EPRI, to increase technology transfer in the area. A DOE reports abstract distribution service is also needed for distribution to those who have previously indicated interest in the subject matter. The list should be updated on a regular basis.

Coordination of all LLRW information systems is greatly needed. Large amounts of information have been generated by individual agencies, but there is no central clearing house and distribution center. Such development would be extremely useful to all workers in LLRW management areas.

Sociopolitical Influences

This area was of concern to nearly all participants in the LLRW meetings attended and sponsored by the assessment staff. There was a very definite expression of frustration due to the feeling that no matter what was done technically, it would not be sufficient because of unsolved sociopolitical problems. The consensus seems to be that technology alone cannot solve the LLRW problems, since technological development work must be done within these strong sociopolitical constraints. The real challenge to technologists is to succeed in developing acceptable technology within this rather negative atmosphere.

The technologists in the LLRW field have suggested no solutions to this problem but, nearly uniformly, they feel that there is a need to stimulate positive public involvement. Forums, rather than computer printouts, are needed. A concerted public relations effort by the appropriate federal agencies could make a difference in the public's acceptance of waste management technologies.

1.2.3 What Disposal R&D is Needed?

The states are faced with the establishment of several new disposal sites in the near future if they are to comply with the impending Compact legislation. At most forums where LLRW disposal was discussed in the recent past, the participants were generally negative about the status of present LLRW disposal site technology. Seldom was there agreement that site hydrogeology is adequately known or assurances that significant problems would not develop in the distant future when a site is closed. These discussions concluded that a new future LLRW disposal site should not be built in the same way as the currently existing ones. A need was recognized for a significant effort to develop better burial ground technologies and practices.

It was pointed out that present design and construction criteria for a site in an arid region such as Richland, Washington, are essentially the same as for one in a high-moisture location such as Barnwell, South

Carolina. Common sense dictates that requirements for protecting public health and safety would be somewhat different at each of these sites. Most probably, the reason they are now so similar is the lack of knowledge about burial ground technology.

If knowledge of the underground conditions were sufficient, the final waste forms disposed of at a burial site could be modified to suit that location. Many of the stringent requirements associated with very wet eastern sites could be relaxed for desert sites, possibly at considerable savings. R. E. Isaacson, representative of Rockwell's Hanford Operations in Richland, Washington, had the following to say on the subject (ORNL 1985):

> I think, in summary, I am still saying that we do not yet know enough about the behaviour of moisture in the soils and how it transports waste from our burial sites. I think this is going to be a very important factor when we start selecting sites for disposal, whether it be in the humid East or the arid West. . . . So again I would plead that we look at the research needs for burial sites in terms of how they behave with the various types of waste forms that we are considering.

When the question of technology needs for future sites was asked of A. Crase, an LLRW Workshop participant from U.S. Ecology, he had the following to say (ORNL 1985):

> We believe that after the Compacts are in place, there will be a great effort exerted by a number of companies to become involved in siting. . . . It may not be necessary to employ a lot of the advanced technology that we see, such as entombment engineered barriers, except for public acceptability. . . . I think the need (advanced technology) is for future siting. . . even though it (the disposal facility) is engineered, you still have to answer the questions under Part 61 (10 CFR 61, 1985) as to what effect it has on the water table, where the water table is, and how it gets there? . . . I believe that (a mechanism for collecting water) would be required in a (future) site.

There was a strong contingent at the LLRW Workshop that felt we should extend the lives of the present disposal sites because of the difficulty in obtaining licenses and public acceptance for a new site. The following statements are typical of that viewpoint:

> Because extending the political acceptance of the sites already in existence is easier and more efficient, we should do everything possible to extend their lifetime by conserving their burial capacity (R. W. Ramsey, Qualcorp, Inc., ORNL 1985).

> We are probably at 1/5 capacity at Richland; I think we have used a total of about 18 acres out of 100. . . . if it were politically acceptable this country can get by with one site. (Arvil Crase, U.S. Ecology, 1985).

It should be noted that all states with burial grounds may not necessarily share this view.

The new types of wastes from decommissioning and decontamination are cause for serious concerns, and so is the increased concentrations of radioactive species due to volume reduction of some wastes shipped to the burial sites. These concerns were articulated at the LLRW Workshop by Roy Person of the NRC (ORNL 1985):

> Decommissioning waste streams are not yet clearly defined. Research needs to be done to characterize waste that would result from the cutting and packaging of hardware, left-over rubble, and other kinds of waste that are generated from decommissioning facilities. This research must be done with an eye toward what will be required by states for disposal as well as optimizing processing.
>
> In the future, decontamination wastes will constitute a much higher percentage of waste requiring disposal. This will occur in an effort to reduce exposures from the buildup of activation products and sludge in nuclear power plants. These wastes will be composed largely of organic chelating agents, which may complex radionuclides and enhance migration in burial site soils.
>
> Since many state Compacts require volume reduction, there will probably be an increased demand for new volume reduction systems as these Compacts are enacted. Additional research will, therefore, be required to ensure safe and effective operation of advanced volume reduction systems and to study the characteristics of the wastes produced.

Virgil Autry, South Carolina Department of Health and Environmental Control (ORNL 1985), shared the same concerns, as indicated in these remarks:

> The NRC's branch technical position on waste forms has established numerous standards with general criteria for determining radionuclide concentrations in waste, in classifying waste,

as well as in establishing standards for proper waste stabilization. We feel at this point, however, that specific methods and guidance should be established to accurately determine the radionuclide concentrations in waste.

In addition to improving radionuclide accountability in waste streams, we also recommend possible R&D studies for LLRW to answer some of the following questions, . . .

The first question that we would like for someone to at least approach is: what are the increased radiological hazards for handling and disposing of wastes that have been subjected to volume reduction (e.g., compaction and incineration)? We do not have very much material on this question today.

The second question is: based on handling and disposing of incinerator ash, residual, and similar wastes at burial facilities, what concentration limits should be established that would require waste stability - for example, solidification or increased containment?

The third question is: what would be an acceptable concentration for chelating agents contained in wastes disposed in burial environments? . . . there has been much discussion about this, and each Compact now, especially in the Southeast, will be faced with ever-increasing burial of wastes-containing chelating agents. Of course, this (chelating) is recognized as a means to increase migration, or the potential to increase migration.

From these and other comments obtained from this assessment, the following questions identifying R&D needs were derived:

1. How do burial sites behave with the waste forms in them?
2. How do waste forms interact with water?
3. What are the mechanisms for transport of materials from the waste forms to the surroundings?
4. How do waste materials migrate through the geological environment?
5. Can mechanisms be developed for collecting, analyzing, and treating water that has been in contact with the waste forms?
6. What techniques can be used for extending the lifetimes of the burial sites that are already created?
7. What will be the effects of decontamination/decommissioning wastes on waste forms and burial-ground mobility of these materials?
8. Are better determinations of radionuclide concentrations in wastes possible to assure proper handling and disposal?
9. What are the consequences of waste volume reduction? The current controversy between the site operators, utilities, states, and the public on this issue needs to be resolved. Analysis of all the

effects of volume reduction is necessary. It is imperative that this be done quickly because of the potentially large impact on burial sites within the newly formed Compacts.

10. Why is site stabilization a continuing problem? Proper stabilization techniques are simply not known and demonstrated at the present time. In nearly all past cases, the functional life of the solid barriers has been shown to be limited and infiltration has occurred. A dominant problem with shallow land burial (SLB) has been the void spaces within trenches. This causes subsidence, followed by water infiltration. Another problem is the site specificity. A stabilization procedure will work for one site but not necessarily for another. The site-specific factors that cause destabilization need to be elucidated by R&D.

1.2.4 Storage Technologies

1.2.4.1 Short-Term Storage

Interim storage (<5 years) at LLRW generator sites will, more than likely, become necessary owing to the impending extension of the LLRW Policy Act. The extension will give an increased time frame for establishing burial sites in the regional Compacts but, in the meantime, the limitations on volume acceptance at the presently existing sites will probably force generator sites to hold some LLRW. The construction of central storage facilities is another possible course of action.

Generic Letter 81-39 (USNRC 1981) provides guidance for interim storage facilities. Wet LLRW having free liquid in excess of burial criteria must be stored in structures or tanks designed to control spills and must have provisions made for reprocessing prior to shipment. Solidified LLRW must meet disposal criteria and have adequate fire protection. For dry LLRW storage, the volume should be minimized, and containers must not support combustion; also the concept of ALARA should be observed. Generic Letter 81-39 discourages storing of unprocessed waste and spent resins that are sufficiently radioactive to generate gases, but the letter strongly encourages solidification of wet waste. Generally, onsite storage requires that waste for storage be prepared as though for shipment.

Areas of concern that require R&D are:

1. monitoring of stored material, particularly resins;

2. fire protection, particularly for polyethylene containers;
3. radiolytic gas generation;
4. radiation-enhanced degradation of polymeric materials;
5. corrosion; and
6. disposal behavior of materials that have been previously stored (for example, what is the behavior of high-density polyethylene that has some radiation-induced oxidative embrittlement, or what are the effects of corrosion on steel containers?).

According to a representative from the Texas Low-level Radioactive Waste Disposal Authority (R. V. Avant), the Texas Legislature has given preference to aboveground storage (LLWMP 1985). The Texas Authority has gone on record as rejecting standard SLB for LLRW waste disposal. Some compromise between aboveground and SLB disposal (e.g., engineered trenches) may be the final solution.

1.2.4.2 Long-Term Storage

There are four types of long-term storage (>5 years) under consideration:

1. large engineered structures;
2. storage modules;
3. shielded casks; and
4. unshielded facilities.

These are presented in more detail by Siskind et al. (1985) and are also discussed in Volume 2, Chapter 6, of this report. The recommendations for R&D by Siskind et al. are in harmony with the concerns expressed by the Workshop participants. These are listed below as potential R&D programs with potential for DOE support:

1. corrosion of materials,
2. radiolytic degradation of materials,
3. effects of temperature and humidity on properties of cement and other waste forms,
4. biodegradative gas generation,
5. radiolytic gas generation, and
6. corrosion rates of carbon steel.

Below are some comments from experts in the LLRW field on the subject of storage.

> Architect-engineers and service companies have provided us with means of storing waste on site. Still to be addressed is the prevention of being forced to accept nonplant water by the states (S. Hobart, EPRI, ORNL 1985).

> Large inconsistencies exist between defense SLB and commercial "excessively engineered systems." We will have to answer these criticisms some time in the future (S. J. Phillips, Rockwell Hanford Operations, LLWMP 1985).

> Storage — we would be wise to let the storage option be available within an overall management plan, and R&D should move to make this option available (G. R. Hill, Southern States Energy Board, LLWMP 1985).

1.2.5 Transportation

Transportation is mostly by truck, with fairly uniform requirements from state to state. The shipping containers are fairly well defined and generally comply with Department of Transportation (DOT) requirements. Possibly the only transportation area where LLRW generators could use assistance is in developing a uniform shipping manifest. This does not appear to be an area where DOE should become more involved.

> In the area of paperwork, DOE has helped by funding the development of the uniform manifest, and they are funding recertification of 210-L (55-gal) drums in response to DOT concerns. Is there a way of ensuring that the publication of a national manifest will encourage its adoption by Compacts, however? (S. Hobart, EPRI, ORNL 1985).

1.2.6 Other Issues

1.2.6.1 Below Regulatory Concern

One of the major concerns of LLRW generators at the LLRW Workshop (ORNL 1985) was the definition of below regulatory concern (BRC) or "de minimis" wastes. Almost unanimously, they stated that one of the most significant things that could occur in the LLRW management area would be the establishment of a firm BRC limit. It is estimated that as much as 1/3 of certain categories of waste [such as low-specific-activity (LSA) wastes and many of the dry active wastes (DAW)] could be disposed of by less costly methods if BRC were properly defined. One utility representative, Joe Walden of Alabama Power Co. (ORNL 1985), had the following to say on this subject,

> We need to get down to the real isssues such as de minimus, which is the bottom line that will give us this 30 and 35% that Udall says we must get to in volume reduction.

W. F. Holcomb, a Workshop participant from the EPA (ORNL 1985), had the following to say about BRC standards:

> We hope to propose a BRC standard next year in conjunction with a low-level standard. . . . Because once you exempt, deregulate or determine a waste is ready to throw out, you are going to throw it anywhere you want. No one is going to control it afterward. It's going to end up in a sanitary landfill, the county dump, or somebody's backyard in a hole. You want to make sure the public is safe. You want to make sure that the public is not going to be down on you every day pounding on you not to do that.

The Canadian position was expressed by D. H. Charlesworth, Atomic Energy of Canada, Ltd. (ORNL 1985). According to Dr. Charlesworth, de minimis waste in Canada is not given disposal in an unrestricted manner. Instead, regulations are less stringent for de minimis wastes than for regular LLRW wastes. Radiation levels of de minimis wastes are not defined so low as to be safe under all conditions. This attitude is in contrast with the current U.S. approach and would encounter the least public resistance.

The discussions surrounding the BRC issue, especially the uncertainty expressed by the EPA representative, point out the need for R&D to answer some of the questions regarding disposal health and safety concerns and allow confident BRC regulations. This viewpoint is shared by EPRI, as expressed by S. Hobart (ORNL 1985):

> Utilities have forced the issue of de minimis or BRC disposal. Vendors have done some work on improved low-level monitors, but, basically, we are still taking risks.

Research and development is needed, for example, in the design of more sensitive instruments for measurements of very low radiation levels and for identifying better methods to separate material from LLRW that could be proven to be no more hazardous than the material now in sanitary landfills. Demonstration of this latter concept is paramount in defining BRC. The Canadian method of creating a special class of material that would be regulated, although less stringently than LLRW, should certainly be considered.

Other pertinent comments on the definition of BRC waste are:

> The (Nuclear Regulatory) Commission cannot give a waste generator a de minimis level, cannot agree upon anything from oil to DAW to any medium. On the other hand, we have a wide gap of disparity, I would think, when we have a Commission that also tells us that 2 nCi/g as a <u>shipper</u> is not regulated (Joe Walden, Alabama Power Co., ORNL 1985).

> In terms of the value you just mentioned, it is 2 nCi/g and it is an activity below which the material is not regulated at all, for purposes of transportation. It is essentially not radioactive. As I said, that only applies to transportation. There is an anomaly in that it is still probably regulated for other purposes. This, I think, stresses the need and importance of establishing limits below regulatory concern for licensing purposes (A. W. Grella, NRC, ORNL 1985).

> At Sequoyah we are working through EPRI to develop a licensing submittal for NRC that would allow us to take all trash with a specific activity of <2 nCi/g to a local sanitary landfill (L. J. Riales, TVA, ORNL 1985).

Riales further commented that significant cost savings and volume reductions (as much as one-third) could result from this effort. From these comments it seems likely that pressure from utilities, industry, and federal organizations could establish 2 nCi/g as the long-awaited BRC definition level. The DOE should assist the commercial sector in this effort by providing technical evidence that this level is indeed acceptable.

1.2.6.2 New Regulatory Concerns

S. Hobart of EPRI discussed [LLRW Workshop (ORNL 1985)] the need for R&D because of the new regulatory concerns:

> Utilities are working with service companies to develop process control plans that ensure proper solidification. . . . Although both EPRI and AIF (Atomic Industrial Forum) have funded some work on estimation of isotopes by using scaling factors, these approaches lead to conservative estimates and do not ensure any accurate accounting of radioactivity placed in the burial trenches. . . . EPRI has been funding some work to improve monitoring techniques. EPRI has also been funding some work on development of a computer program to predict hydrogen-generation from waste. . . . We need to ensure that the waste forms will be stable at the burial site, in the burial trench, over the long term. Perhaps the most critical short-term question is, how can we be assured the Compact requirements for waste forms will be uniform and reasonable?

1.2.6.3 Mixed Wastes

A detailed study is needed to examine the processes that produce mixtures of radioactive and chemically hazardous wastes and to search for reasonable alternative processing that will produce less (or none) of this undesirable material. Direct substitution or regeneration and/or recycle of certain selected materials may be viable options. Specific examples of materials that should be eliminated, if possible, are PVCs, chemical solvents, and chelating agents. An example of a promising technology that merits further R&D support is the use of microwave energy for the destruction of PVC materials.

Comments from the LLRW Workshop concerning the disposal of mixed wastes are given below:

> On November 8, 1985, U.S. Ecology will no longer accept scintillation fluid in any form. Now, where does it go? Regulated or deregulated, it does not matter. We, as a burial site operator, cannot conform to retroregulations as they are written and handle radioactive waste. We cannot morally subject our employees to opening containers to verify waste forms and the chemical constituents thereof. I am not sure that there is a radiochemistry lab in the country that could perform this analysis for us. It also involves a retromanifest; it also involves dual lining in trenches. We urgently need a definition of mixed wastes and who regulates what (A. Crase, U.S. Ecology, ORNL 1985).

> According to the definitions being considered among the federal agencies, mixed wastes could encompass as much as 95% of the waste that is currently generated, or it could encompass as little as 3%. . . .

> The small generators, of which there are about ten times more (in number) than utility generators, do not appear to have the large economic base to meet the more demanding regulations concerning mixed wastes. . . .
>
> Currently, there are several categories of wastes that have no home, which I call orphaned wastes. One of those is, in normal parlance, Class D waste, that is, greater than Class C. It is somewhere between high-level waste, which is not defined by EPA, and low-level waste. Neither the state of South Carolina nor the state of Washington will receive greater than Class C waste without additional information regarding the safety of that classification for shallow-land burial (N. Kirner, Department of Health and Social Services, State of Washington, ORNL 1985).

1.2.6.4 Technology Transfer/Information Exchange

V. Autry, of the South Carolina Department of Health and Environmental Control, commented during the LLRW Workshop (ORNL 1985):

> Also, there is a need for informational systems for the host states, the Compact Commissions, the burial sites, and the federal agencies and many of their contractors. A national data base system should be established, and I understand that there is work toward this end now being done.

1.2.6.5 International R&D Implications

C. A. Hutchison, of the Société Generale pour les Techniques Nouvelles (SGN) stated the following:

> Forty-one operating reactors generate 60% of France's electricity today. That will go to 75% in a few years (LLWMP 1985).

With such a heavy load imposed on the French waste disposal system, they still seem to have developed the best LLRW disposal in the world today. Some speculated that most of the U.S. waste disposal problems would be solved if we would adopt a similar program here. The system was described in detail at the LLRW Conference in Las Vegas, Nevada. In a detailed paper provided to the attendees (LLWMP 1985), Hutchison described this "Integrated Waste Management System" as follows:

> Central receiving stations will be placed near disposal facilities and shipment will be by rail and truck. Total control is required by manifesting from generation to final disposal with frequent QA audits. The Earth-Mounded Concrete Bunker (EMCB) concept will be used. This is basically a series of below-ground concrete "cells and canyons" for containing the most radioactive wastes; drums of the less radioactive material are stored on top of the concrete pad which makes up the roof. The entire monolith is then covered with a mound of impermeable earth, such as certain types of clays. Water diversion and collection systems are installed and continuously monitored. This allows localization of any leaks in cells or canyons which can then be repaired without digging up the entire unit. Process equipment is onsite for processing contaminated material arising from such leaks. The first of the EMCBs will be operational in the 1990-1991 period.

The West German waste management position was presented during a discussion period at the LLRW Workshop.

> In West Germany there is no shallow land burial and no low-level waste disposal at all — all their material is stored on site. They ship to a regional nuclear research center, where it is volume reduced either by compaction, incineration, or an appropriate process. It is then packaged, most often solidified, and returned to them.
>
> I would like to suggest that volume reduction on an individual utility basis is not the way we should be looking at this. We should be looking at volume reduction centers. . . . I further submit that these regional centers ought to be coupled to the burial sites. Some of the States may not agree with me, but that would give them total control (within the Compact structure), a total waste management center, and they would not have to be concerned about increasing classification from C to greater than C, or from B to C, or from A to B, if it were not necessary. As everything came in, it would be volume reduced, as appropriate for the waste form and type, and then placed in the ground out the back door. . . . within the frame-work of the Compacts, we are talking about five or seven sites now, so we are talking about reasonable transportation issues (A. Gould, Florida Power and Light, ORNL 1985).

R. Kohout of Ontario Hydro discussed Canadian LLRW management practices at the LLRW Workshop (ORNL 1985):

> I am from Canada and we have practiced on-site storage since we started the nuclear program. We do understand that once you introduce engineered structures into storage, retrievable

> storage or retrievable disposal, you start to worry about volume. We have developed about the fifth generation of storage structures, engineered storage structures, which are very inexpensive, yet we still feel that volume reduction is a very important segment in our waste management.

This discussion was supplemented by D. H. Charlesworth, Atomic Energy of Canada, Ltd. (ORNL 1985):

> Our Atomic Energy Control Board, which is our regulatory body, has made it known that the fewer the sites the better as far as their input into the situation, and we are also pushed in that direction because the scale of operation is small enough that the less you subdivide it, the more economically viable it is. But beyond that, I think what is just as important for us is that existing sites can be operated. New sites are very hard to come by. . . .

Dr. Charlesworth also added:

> Is there anything but storage going on at the present time? Do we really expect to walk away from any site?

1.2.6.6 Sociopolitical Issues

H. L. Mencken once wrote that most people think that all complex problems have a simple solution. And then he added the statement, "but it is usually wrong." This quote seems appropriate for the complex sociopolitical issues affecting LLRW management. The situation is recognized by many in the field:

> LLRW (management) is not a technical problem; it is a political one. Public opposition (to LLRW handling and disposal) is a given. . . . We are not taking prescriptive action, we are taking reactive action. . . . We need to do the former to solve our waste problems (R. V. Avant, Jr., Texas Low-Level Radioactive Waste Disposal Authority, LLWMP 1985).

To paraphrase Mr. Avant, "We need to get on with solving the technical problems within the political framework."

Another attendee of the LLWMP Meeting (R. F. Patton, Midwest Intersory Low-Level Radioactive Waste Commission, LLWMP, 1985) also concluded that SLB was technically feasible but politically unacceptable as a disposal technique for LLRW:

> The populace in our region does not want shallow land burial. . . . If voted in our region it would not go.

A commercial burial ground operator observed that the EPA and NRC tried for a "Memorandum of Understanding" regarding mixed wastes (J. J. Scoville, President, U.S. Ecology, LLWMP 1985). The effort failed, owing to "significant differences"; as a result, the EPA now requires the filing of Part B of their permit application in order to operate an LLRW site as an RCRA site. This burial ground operator proposed a legislative amendment that would give the NRC sole responsibility for LLRW disposal facilities.

However, a compromise addition that was attached to the original proposal requires that, within 90 d of enactment of Compact legislation, the EPA, with NRC concurrence, will produce a list of substances to be regulated by the EPA. This, of course, leaves the dual regulation authority that U.S. Ecology would prefer to avoid.

1.3 DEMONSTRATION

The DOE is in a unique position to offer significant assistance to LLRW generators. Because of the in-house expertise developed at DOE high technology facilities and the comprehensive DOE technology applications programs, they can provide technical information as outlined earlier. In addition, DOE has the facilities and the funding to provide large-scale demonstrations of these technologies. In fact, the DOE will be developing waste disposal techniques in compliance with various internal directives (DOE 1984). In accordance with these regulations, the DOE will comply with the intent of RCRA within 5 years. There is further impetus for R&D in the fact that DOE is currently encountering resistance from the State regulators and EPA in establishing new burial sites to replace rapidly filling ones. While the RCRA is related only to chemically hazardous wastes, it has important connotations for "mixed" wastes. This was one of the most pressing problems identified by this assessment. The DOE demonstrations of new hazardous waste technologies (e.g., incineration) are appropriate for LLRW management also, since the two types of waste have many similarities. While the LLRW generators are reluctant to adapt unproven high technology, they would readily accept technologies that have been proven by large-scale demonstrations on DOE wastes. It is recommended that DOE create a formal liaison program with EPRI (and perhaps others) to assure that any advantages that might be gained from their LLRW technology demonstration program would accrue to the commercial LLRW generators.

1.4 CONCLUSION

A summation of the commitment felt by workers in the LLRW management field may be found in this statement by S. Hobart of EPRI (ORNL 1985):

> I want to end with the thought that there is an issue beyond cost-benefit in the search for LLRW solutions, the issue of stewardship. This is the earth on which we live. We have the responsibility of managing radioactive waste to ensure the safety of our world and future generations. We also, however, have the responsibility to convey our dedication for those solutions to the public. By assuaging their concerns, we will not preclude the use of the most environmentally safe energy technology today, nuclear power.

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