Improving the Regulation and Management of Low-Activity Radioactive Wastes: Interim Report on Current Regulations, Inventories, and Practices

Committee on Improving Practices for Regulating and Managing Low-Activity Radioactive Wastes, National Research Council

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Interim Report on Current Regulations, Inventories, and Practices

Committee on Improving Practices for Regulating and Managing Low-Activity Radioactive Wastes

Board on Radioactive Waste Management

Division on Earth and Life Studies

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Preface

This study began with the observation by members of the Board on Radioactive Waste Management (BRWM) that low-activity radioactive wastes in the United States are managed under a patchwork of regulations that have evolved over the past 60 years—since the beginning of large-scale production of nuclear materials under the Manhattan Project. Today a broad spectrum of low-activity wastes originates from nuclear power utilities; the use of radioisotopes in industry, medicine, and research; recovery of mineral resources (mining, oil and gas production); and Department of Energy (DOE) sites.

Because statutes and regulations that control low-activity waste are based on the origin of these wastes, rather than their radiological properties, regulation may be overly restrictive in some cases, leading to excessive costs and other burdens on the waste generator. In other cases, some wastes may present greater potential risks to the public than are generally recognized. The BRWM therefore believed that a National Research Council study of current low-activity waste management and regulation, and an assessment of options for improving the current system would be valuable for state and federal policy makers, waste generators and regulators, and concerned members of the public.

This interim report concludes the first half of the study by providing an overview of low-activity waste characteristics, inventories, management and disposal practices, and the federal and state authorities that control these wastes. The committee has attempted to organize a great deal of diverse information into a succinct presentation and set of findings that will provide a sound basis for the final report, which will describe and assess options for improvements.

The committee would like to recognize the five sponsors that provided financial support at the beginning of this study:

Army Corps of Engineers
Department of Energy
Environmental Protection Agency
Nuclear Regulatory Commission
Southeast Compact Commission.

Informative site visits were arranged by Rudy Guercia, DOE Richland Operations Office, Hanford, Washington site; Mike Ault, U.S. Ecology, also at the Hanford site; Ken Alkema, Envirocare, Clive, Utah; and Louis Dell'Orco, Army Corps of

Engineers, FUSRAP sites near St. Louis, Missouri. The committee also thanks the individuals who made presentations at our public meetings (see Appendix A).

The work of this committee was ably assisted by members of the BRWM staff. John Wiley, study director, assisted and advised the committee from its inception through review of this interim report. Darla Thompson, senior research assistant, provided the extensive documentation and other data resources used by the committee. Angela Taylor and Toni Greenleaf provided prompt and efficient assistance with logistical and financial matters.

Finally, I want to thank the members of the committee for their dedication and diligence. I especially appreciate the leadership skills and technical insights provided by Michael Ryan, vice-chairman. Although of diverse backgrounds and expertise, the committee respected the overall goal of this initial phase of the study, and each made significant contributions. I look forward to working with the committee and staff in completing this study and the final report.

David Leroy
Chair

List of Report Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council (NRC) Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The content of the review comments and draft manuscript remains confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their participation in the review of this report:

David Adelman, University of Arizona
John Ahearne, Sigma Xi and Duke University
Jan Beyea, Consulting in the Public Interest
Allen Croff, Oak Ridge National Laboratory
Ron Fraass, Conference of Radiation Control Program Directors
Jill Lipoti, New Jersey Dept. of Environmental Protection
Paul Rennick, Rennick and Associates
John Vincenti, The Pennsylvania State University

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Chris Whipple of ENVIRON International. Appointed by the National Research Council, he was responsible for making certain that an independent examination of this report was carried out in accordance with NRC procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the NRC.

Contents

Executive Summary

Low-activity radioactive wastes include a broad spectrum of materials for which a regulatory patchwork has evolved over almost 60 years. These wastes present less of a radiation hazard than either spent nuclear fuel or high-level radioactive waste.[1] Low-activity wastes, however, may produce potential radiation exposure at well above background levels and if not properly controlled may represent a significant chronic (and, in some cases, an acute) hazard.[2] For some low-activity wastes the present system of controls may be overly restrictive, but it may result in the neglect of others that pose an equal or higher risk.

The purpose of this interim report is to provide an overview of current low-activity waste regulations and management practices (see Sidebar ES-1). In developing this overview, the committee[3] has sought to identify gaps and inconsistencies that suggest areas for improvements. This initial fact-finding phase of the project led the committee to the findings that conclude this interim report. The committee will assess options for improving the current practices and provide recommendations in its final report.

In initiating this study, the Board on Radioactive Waste Management used the term "low-activity waste" to denote a spectrum of radioactive materials declared as wastes from a variety of activities—national defense, nuclear power, industry, medicine, research, and mineral recovery.[4] Given this broad charter, the committee sought to develop a concise list of categories that would include low-activity wastes from essentially all sources,[5] yet by focusing on their inherent radiological properties rather than their ori-

[1] See Disposition of High-Level Waste and Spent Nuclear Fuel: The Continuing Societal and Technical Challenges (NRC, 2001a) and One Step at a Time: The Staged Development of Geologic Repositories for High-Level Radioactive Waste (NRC, 2003).

[2] See Health Effects of Exposure to Low Levels of Ionizing Radiation: BEIR V (NRC, 1990).

[3] The Committee on Improving Practices for Regulating and Managing Low-Activity Radioactive Waste is referred to as "the committee" throughout this report. Short biographies of the committee members are given in Appendix F.

[4] The Board intended the term "low-activity waste" to be more inclusive than "low-level waste," which has a specific definition under the Nuclear Waste Policy Act (see Chapter 2). The term "low-activity waste" has sometimes been applied to the lower activity fractions of Department of Energy (DOE) tank waste. The committee does not use the term in this sense.

[5] The committee did not include waste containing only short-lived radioactivity (on the order of a year or less), which simply decays away during storage. These wastes do not present long-term management or disposal challenges.

gins, emphasize gaps and inconsistencies between their current regulation and management and their actual radiological hazards. The committee agreed that the following is an instructive and inclusive categorization of the wastes to be addressed:

- Wastes containing types and quantities of radioactive materials that fall well within the Nuclear Regulatory Commission (USNRC) classification system for low-level waste, e.g., Class A, B, and C (see Chapters 2, 3 and Appendix B). These include wastes from nuclear utilities, other industries, medicine, and research, which are disposed in USNRC-licensed, commercially operated facilities ("commercial low-level waste"), and similar wastes produced and disposed at Department of Energy (DOE) sites ("defense low-level waste").
- Slightly radioactive solid materials—debris, rubble, and contaminated soils from nuclear facility decommissioning and site cleanup. They arise in very large volumes but produce very low or practically undetectable levels of radiation. They fall at the very bottom of USNRC Class A (the lowest of the classes).
- Discrete sources—out-of-service radiation sources and associated materials from industrial, medical, and research applications. Although defined by statute as low-level waste, they may emit high enough levels of radiation to cause acute effects in humans or serious contamination incidents. Larger sources may exceed USNRC Class C (the highest of the classes).
- Uranium and thorium ore processing wastes. These wastes have been produced in large volumes from the recovery of uranium and thorium for nuclear applications. Their radiological hazards arise not only from radioactive uranium and thorium isotopes, but also from their radioactive decay products, especially radium, which can migrate into drinking water, and radon, which is a gas.
- Naturally occurring and technologically enhanced naturally occurring radioactive materials (NORM and TENORM) wastes. These wastes arise coincidentally from the recovery of natural resources (extraction of rare earth minerals and other mining operations, oil, and gas) and water treatment. Like uranium and thorium wastes, they arise in large volumes and their radiological hazards result from uranium, thorium, and their radioactive decay products, radium and radon.

Throughout this report the committee will use these categories to illustrate gaps and inconsistencies in the current regulations for wastes with very different levels of radioactivity, volumes, and radioactive half-lives; and inconsistencies in regulating wastes that are radiologically similar to each other.

At least 12 federal statutes apply to low-activity wastes. The broadest of these is the Atomic Energy Act (AEA), which defines wastes in the first four categories listed above as "byproduct" materials and provides federal authority for their regulation. Wastes in the first three categories meet the definition of low-level waste (LLW) given in the Nuclear Waste Policy Act (NWPA) of 1982, as amended. The NWPA provides no statutory upper or lower limit on the radioactivity in low-level wastes. Uranium- and thorium-contaminated wastes produced after the Uranium Mill Tailings Radiation Control Act (UMTRCA) was passed in 1978 must be disposed in licensed radioactive waste facilities.[6] There are more disposal options for uranium- and thorium-contaminated wastes

[6] Strictly speaking, UMTRCA also applies to wastes at facilities licensed by the Nuclear Regulatory Commission before 1978 (see Chapter 2).

produced prior to UMTRCA, which are managed under the Formerly Utilized Sites Remedial Action Program (FUSRAP). Thus the disposal options for FUSRAP and UMTRCA wastes differ even though the materials are the same (or similar).

Low-level wastes generated or disposed in the commercial sector are regulated by the USNRC under its authority to license nuclear facilities and the possession of nuclear materials. The Environmental Protection Agency (EPA) has authority to regulate environmental radiation exposure as well as hazardous chemical wastes. Wastes that contain both radionuclides and hazardous chemicals are referred to as "mixed wastes" and may be subject to regulation by both the USNRC and EPA. The DOE is self-regulating for defense wastes on its own sites. The Department of Transportation regulates the shipment of radioactive materials while the USNRC has the authority to regulate certain packages for transportation of nuclear materials.

The states have three important responsibilities with regard to low-activity wastes:

1. The Low-Level Radioactive Waste Policy Act of 1980, as amended, makes each state responsible for disposing of its own LLW and encourages the formation of state compacts (congressionally ratified agreements among groups of states) for providing disposal facilities.[7]
2. States may assume portions of the USNRC's regulatory authority by becoming a USNRC Agreement State. Thirty-three states are Agreement States, including the three that currently host LLW disposal facilities (South Carolina, Utah, and Washington).
3. The states regulate non-AEA wastes because these wastes are not covered by federal statutes. An especially important role for the states is the regulation of NORM and TENORM wastes from a number of activities, including mining, oil and gas production, and water treatment.

Of the wastes described in this interim report, LLW from DOE and commercial nuclear facilities have received the most attention from regulators and the public. LLW in the form of debris, rubble, and contaminated soils from facility decommissioning and site cleanup constitutes much larger volumes than LLW from operational facilities, but it generally contains very little radioactive material. Conversely, discrete radioactive sources that are no longer useful also meet the definition of LLW although they may contain highly concentrated radioactive materials.

Millions of cubic meters of tailings and other wastes from mining and processing uranium and thorium ores are stored or disposed in piles near their origin. Like LLW, uranium and thorium wastes are subject to the AEA, but concern about them comes mainly from citizens living near these wastes. NORM and TENORM wastes contain the same long-lived radioactive constituents as uranium and thorium wastes and arise in equally large or larger volumes. NORM and TENORM wastes are not subject to the AEA, and there is less consistency in their regulation and little public concern about them.

[7] As discussed in Chapter 3, the Act did not lead to establishment of new disposal sites as intended.

FINDINGS

In general, the committee believes that there is adequate statutory and institutional authority to ensure safe management of low-activity wastes, but the current patchwork of regulations is complex and inconsistent—which has led to instances of inefficient management practices and possibly in some cases increased risk overall. Existing authorities have not been exercised consistently for some wastes. The system it likely to grow less efficient if the patchwork approach to regulation continues in the future.

Finding 1

Current statutes and regulations for low-activity radioactive wastes provide adequate authority for protection of workers and the public.

In its fact-finding meetings, site visits, and review of relevant literature, the committee found no instances where the legal and regulatory authority of federal and state agencies was inadequate to protect human health. This finding is consistent with previous studies by the National Academies and the National Council on Radiation Protection and Measurements (NCRP) (NRC, 1999a, 2002a; NCRP, 2002). Some states, however, have chosen not to exercise regulatory authority over NORM and TENORM wastes. The USNRC has determined not to regulate certain pre-1978 uranium and thorium wastes. The EPA has so far not exercised its authority under the Toxic Substance Control Act to regulate non-AEA radioactive wastes. In addition, some wastes have not been adequately controlled in spite of the existence of regulatory authority. Incidents in which out-of-use sealed sources were melted with scrap steel have been expensive, led to very conservative practices in the steel and nuclear industries, and fueled public distrust in the regulatory system (NRC, 2002a; HPS, 2002; Turner, 2003).

Finding 2

The current system of managing and regulating low-activity waste is complex. It was developed under a patchwork system that has evolved based on the origins of the waste.

In its information-gathering the committee received a clear message from agencies responsible for managing and regulating low-activity waste: A more consistent, simpler, performance-based and risk-informed approach to regulation is needed (see Chapter 4, Sidebar 4.3). Many committee members themselves had difficulty in understanding the regulations well enough to discuss the system and its applications. Similarly the NCRP found that the current waste classification systems "are not transparent or defensible" and that the "classification systems are becoming increasingly complex as additional waste streams are incorporated into the system" (NCRP, 2002, p. 65).

Findings 3 and 4

Certain categories of low-activity wastes have not received consistent regulatory oversight and management.

Current regulations for low-activity wastes are not based on a systematic consideration of risks.

Regulations focused on the wastes' origins have led to inconsistencies relative to their likely radiological risks. NORM and TENORM are not regulated by federal agencies, and state regulation of these wastes is not consistent. Nevertheless, these wastes may have significant concentrations of radioactive materials as compared to some highly regulated waste streams (e.g., from the nuclear industry). As described in Chapter 4, NORM wastes routinely accepted at a landfill triggered a radiation monitor intended to ensure that rubble from a decommissioned nuclear reactor meets very strict limits on its radioactivity.

Uranium mining and processing wastes, which are radiologically similar to NORM wastes, are regulated by their date of origin. Federal regulations do not prohibit ore processing residuals at facilities that were not under license by the USNRC before the 1978 passage of UMTRCA from being disposed in landfills. However, mill tailings generated after UMTRCA, must be disposed in licensed radioactive waste facilities.

In addition to inconsistencies in regulating the radiological risks, current regulations generally overlook trade-offs between radiological and non-radiological risks. Very large (100,000 cubic meter) volumes of slightly contaminated soil and debris, and very heavy nuclear reactor components are being transported long distances for disposal. In developing current requirements for how low-activity wastes are managed or disposed, worker risks in excavating, loading, and unloading large-volume wastes; risks of transportation accidents; and environmental risks and costs (e.g., consuming large amounts of fossil fuel) have not been analyzed and compared in a systematic way to radiological risks.

PUBLIC CONCERNS REGARDING LOW-ACTIVITY WASTES: AN ISSUE FOR THE FINAL REPORT

On beginning this study, the committee was aware that there is persistent and widespread public concern with all aspects of radioactive waste management and disposal (NRC 1996, 2001a, 2002a, 2003; GAO, 1999; Dunlap et al., 1993). During the committee's open sessions, members of the attending public expressed considerable lack of trust in the low-activity waste regulatory system due to its complexity, inflexibility, and inconsistency. These factors have apparently raised doubts about the current system's capability for protecting public health.

The task of this interim report was to develop an overview of current regulatory and management practices for low-activity waste, and thus set the stage for the committee's final report, which will assess policy and technical options for improving the current practices. The assessments will include risk-informed options, and the committee strongly believes that issues of public trust and risk perception will be important considerations in the final report.

SIDEBAR ES-1 PURPOSE OF THIS REPORT

This study was initiated by the National Academies' Board on Radioactive Waste Management. Due to financial constraints, the study was divided into two phases. This interim report, which concludes phase one, addresses current low-activity waste regulations and practices according to the following parts of the study's task statement:

(1) Using available information from public domain sources, provide a summary of the sources, forms, quantities, hazards, and other identifying characteristics of low-activity waste in the United States; and
(2) review and summarize current policies and practices for regulating, treating, and disposing of low-activity waste, including the quantitative (including risk) bases for existing regulatory systems, and identify waste streams that are not being regulated or managed in a safe or cost effective manner.

Phase two will assess options for improving regulations and practices (see Chapter 1, Sidebar 1.1) and provide a final report.

1
Introduction

This study was initiated by the National Academies' Board on Radioactive Waste Management (the Board), which observed that statutes and regulations administered by the state and federal agencies that control low-activity wastes have developed in an ad hoc manner over almost 60 years. They usually reflect the waste's origin from national defense, nuclear power, industrial, institutional, or natural sources rather than its radiological hazard. Inconsistencies in the regulatory patchwork or its application have led to very restrictive controls for some low-activity wastes but the relative neglect of others.

The purpose of this interim report is to provide an overview of current regulations and management practices, in conformance with items 1 and 2 of the project's task statement (see Sidebar 1.1). In developing the overview, the committee[1] has sought to identify gaps and inconsistencies that would suggest areas for significant improvements. This initial fact-finding phase of the project led the committee to the findings that conclude this report. The committee will address item 3 of the task statement and provide recommendations in its final report.

WHAT ARE LOW-ACTIVITY RADIOACTIVE WASTES?

In initiating this study, the Board used the term "low-activity waste" to denote a spectrum of radioactive materials declared as wastes from a variety of national defense and private sector activities.[2] These low-activity wastes generally contain lower levels of radioactive material and present less of a hazard to public and environmental health than either spent nuclear fuel or high-level waste from chemical processing of spent fuel, both

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[1] The Committee on Improving Practices for Regulating and Managing Low-Activity Radioactive Waste is referred to as "the committee" throughout this report. Short biographies of the committee members are given in Appendix F.

[2] The Board intended the term "low-activity waste" to be more inclusive than "low-level waste," which has a specific definition under the Nuclear Waste Policy Act (see Chapter 2). The term "low-activity waste" has sometimes been applied to the lower activity fractions of Department of Energy (DOE) tank waste. The committee does not use the term in this sense.

SIDEBAR 1.1 TASK STATEMENT

The objective of this study is to evaluate options for improving practices for regulating and managing low-activity radioactive waste in the United States. The study will focus on the following three tasks:

1. Using available information from public domain sources, provide a summary of the sources, forms, quantities, hazards, and other identifying characteristics of low-activity waste in the United States;
2. Review and summarize current policies and practices for regulating, treating, and disposing of low-activity waste, including the quantitative (including risk) bases for existing regulatory systems, and identify waste streams that are not being regulated or managed in a safe or cost effective manner; and
3. Provide an assessment of technical and policy options for improving practices for regulating and managing low-activity waste to enhance technical soundness, ensure continued protection of public and environmental health, and increase cost effectiveness. This assessment should include an examination of options for utilizing risk-informed practices for identifying, regulating, and managing low-activity waste irrespective of its classification.

of which are highly hazardous and tightly regulated.[3] However, low-activity wastes may contain naturally occurring or other long-lived radionuclides at well above background levels, and it may represent a significant chronic (and, in some cases, an acute) hazard to public and environmental health.[4]

Given this broad charter, the committee sought to develop a concise list of categories that would include low-activity wastes from essentially all sources,[5] yet by focusing on their inherent radiological properties rather than their origins, emphasize gaps and inconsistencies between their current regulation and management and their actual radiological properties. The committee agreed that the following is an instructive and inclusive categorization of the wastes to be addressed:

- Wastes containing types and quantities of radioactive materials that fall well within the Nuclear Regulatory Commission (USNRC) classification system for low-level waste, e.g., Class A, B, and C (see Chapters 2, 3 and Appendix B). These include wastes from nuclear utilities, other industries, medicine, and research, which are disposed in USNRC-licensed, commercially operated facilities ("commercial low-level waste"), and similar wastes produced and disposed at Department of Energy (DOE) sites ("defense low-level waste").
- Slightly radioactive solid materials—debris, rubble, and contaminated soils from nuclear facility decommissioning and site cleanup. They arise in very large volumes but

[3] See Disposition of High-Level Waste and Spent Nuclear Fuel: The Continuing Societal and Technical Challenges (NRC, 2001a) and One Step at a Time: The Staged Development of Geologic Repositories for High-Level Radioactive Waste (NRC, 2003). Transuranic wastes, which are controlled by the DOE, are addressed in several other National Research Council reports (NRC, 2001b, 2002b, 2002c) and are not included in this study.

[4] See Health Effects of Exposure to Low Levels of Ionizing Radiation: BEIR V (NRC, 1990).

[5] The committee did not include waste containing only short-lived radioactivity (on the order of a year or less), which simply decays away during storage. These wastes do not present long-term management or disposal challenges.

produce very low or practically undetectable levels of radiation. They fall at the very bottom of USNRC Class A (the lowest of the classes).

- Discrete sources—out-of-service radiation sources and associated materials from industrial, medical, and research applications. Although defined by statute as low-level waste, they may emit high enough levels of radiation to cause acute effects in humans or serious contamination incidents.[6] Larger sources may exceed USNRC Class C (the highest of the classes).
- Uranium and thorium ore processing wastes. These wastes have been produced in large volumes from the recovery of uranium and thorium for nuclear applications. Their radiological hazards arise not only from the radioactive uranium and thorium isotopes, but also from their radioactive decay products, especially radium, which can migrate into drinking water, and radon, which is a gas.
- Naturally occurring and technologically enhanced naturally occurring radioactive materials (NORM and TENORM) wastes. These wastes arise coincidentally from the recovery of natural resources (extraction of rare earth minerals and other mining operations, oil, and gas) and water treatment. Like uranium and thorium wastes, they arise in large volumes and their radiological hazards result from uranium, thorium, and their radioactive decay products, radium and radon.

As will be discussed later in this report, wastes in the first four categories fall under the Atomic Energy Act, which provides authority for their control by federal agencies. Wastes in the first three categories all meet the statutory definition of low-level waste, although their physical and radiological properties, and hence their hazards, vary greatly. Wastes in the last two categories are similar in their physical and radiological properties, but the federal government has regulatory authority over the former and the states have authority over the latter. Table 1.1 summarizes the committee's categorization of low-activity wastes.

APPROACH TO THE TASK STATEMENT

In developing its overview of current inventories, regulations, and management practices for this interim report (parts 1 and 2 of the task statement), the committee encountered a massive amount of literature on federal and state regulations, inventory data, and management practices. This report does not attempt to replicate the detailed information already available; rather, the report summarizes the information that led to the committee's findings and points to possible improvements in the overall regulatory structure, which the committee will examine in its final report (part 3 of the task statement).

Information Sources

The main sources of information for this interim report included:

[6] For completeness, radium sources and accelerator-produced material can be included in this category although they do not meet the statutory definition of low-level waste (see Chapter 2).

TABLE 1.1 The Committee's Categorization of Low-Activity Wastes

Category	Principal Origins	Typical Examples	Reason for Category
Defense and commercial low-level waste	Operations at DOE sites, nuclear power and research reactors, medical facilities	Trash, equipment, construction materials, process residues, soils	These are the wastes that are typically described as low-level wastes and disposed in near-surface facilities at DOE or commercial sites. They meet the statutory definitions of Atomic Energy Act 11e.(1) byproduct materials and the exclusionary definition of "low-level waste" under the Nuclear Waste Policy Act (NWPA, see Chapter 2). The relatively short-lived radioactive isotopes and activity levels of the waste fit into USNRC Classes A, B, or C (See Chapters 2 and 3).
Slightly radioactive solid materials	Decommissioning of nuclear facilities at DOE and civilian sites, and site clean-up	Debris, rubble, construction materials, soils	These wastes represent the low end of the spectrum of materials defined, regulated, and managed as low-level waste. They produce very low or essentially undetectable levels of radiation, but they arise in very large volumes. The descriptor "slightly radioactive solid materials" was introduced in NRC, 2002a.
Discrete sources	Applications of radiation sources in industry, medicine, and research	Out of use sealed radiation sources or material used to make the sources, accelerator-produced radioactive materials	These wastes represent the high end materials that meet the statutory definitions of "low-level waste," although they may be capable of producing acute radiation effects in humans and serious contamination incidents. They may exceed the USNRC Class C limit for waste that is acceptable for near-surface disposal.
Uranium and thorium ore processing wastes	Recovery of uranium or thorium for DOE or civilian nuclear applications	Mining and milling tailings, process residues, soils, equipment	These low-activity wastes do not meet the NWPA definition of "low-level waste," but they are federally regulated under the AEA definition 11e.(2) byproduct materials (see Chapter 2). Their radioactivity arises from long-lived, natural uranium and thorium isotopes and their decay products. There are large volumes of these wastes, some dating back to the Manhattan Project (see Chapter 3).
Naturally occurring and technologically enhanced naturally occurring radioactive materials (NORM and TENORM)	Recovery and processing of mineral resources unrelated to nuclear applications, municipal water treatment	Commercial ore mining residues, phosphate mining and fertilizers, scale and sludge from oil and gas production, water treatment filters, resins, and sludges	These low-activity wastes meet neither the NWPA definition of "low-level waste," nor the AEA definition 11e.(2) byproduct materials—hence they are not directly subject to federal regulation (see Chapter 2). The origin of the radioactivity in these wastes and their large volumes are comparable to uranium and thorium ore processing wastes.

- Information-gathering meetings and site visits,
- Previously published studies, and
- Internet material.

First-hand information was provided to the committee at five information-gathering meetings and three site visits. This information was presented by the study sponsors, representatives of other regulatory and operating organizations, local officials, and members of the public (see Appendix A). The committee held its first information-gathering meeting in Washington, D.C. on December 4-5, 2002, to receive presentations from study sponsors and comments from other interested individuals. Information-gathering and site visits included Richland, Washington (Hanford and U.S. Ecology), on February 6-7, 2003, and Salt Lake City, Utah (Envirocare of Utah), on April 16-17, 2003. Four committee members visited FUSRAP[7] sites near St. Louis, Missouri, on May 12, 2003. A final information-gathering meeting was held in Washington, D.C. on June 12, 2003.

The following published studies served as cornerstones for the committee's deliberations and findings:

- *Risk-Based Classification of Radioactive and Hazardous Chemical Wastes* was published in 2002 by the National Council on Radiation Protection and Measurements (NCRP). This report found that the existing patchwork system of regulations is inconsistent and becoming increasingly complex. It presents the NCRP's recommendations for a waste classification system that would apply to any waste containing radionuclides or hazardous chemicals (NCRP, 2002).
- *The Disposition Dilemma: Controlling the Release of Solid Materials from Nuclear Regulatory Commission-Licensed Facilities* was published in 2002 by the National Academies' Board on Energy and Environmental Systems. This study was requested by the USNRC to inform rulemaking on disposition of very-low-activity wastes, mainly steel and concrete from commercial nuclear reactor decommissioning. The study found that the USNRC's current approach of case-by-case clearance decisions was protective of public health, but inconsistently applied. The study recommended use of a dose-based standard in evaluating disposition options (NRC, 2002a).
- *Evaluation of Guidelines for Exposures to Technologically Enhanced Naturally Occurring Radioactive Materials* was published in 1999 by the National Academies' Board on Radiation Effects Research. This study was requested by the Environmental Protection Agency (EPA) and reflected the agency's awareness of the hazards of NORM and attempts to develop regulatory guidelines. The study found that differences among existing guidelines were based on policy judgments rather than on scientific information (NRC, 1999a).
- *United States of America National Report: Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management* summarizes policies, practices, regulations, and inventory of all declared wastes in the United States. The report was prepared by the DOE, EPA, USNRC, and State Department to meet reporting requirements of the Joint Convention, which was ratified and signed by President Bush in April 2003 (DOE, 2003).

[7] Formerly Utilized Sites Remedial Action Program (see Chapter 3).

The committee also used information from the Manifest Information Management System (MIMS) that provides data on waste sent to commercial disposal facilities over past 12 years (http://mims.apps.em.doe.gov) and the Central Internet Database (CID) that provides information on DOE wastes (http://cid.em.doe.gov).

Outline of this Report

The committee itself had difficulty in comprehending the many complicated statutes and regulations that apply to low-activity wastes. The committee therefore felt it would be useful to begin this interim report by describing these statutes and regulations in Chapter 2. Chapter 3 summarizes low-activity waste inventories, hazards, and management and disposal practices according to the present regulatory system. Chapter 4 gives the committee's views and findings with illustrative examples.

2
The Statutory and Regulatory Context for Low-Activity Waste Management

From the discovery of radioactivity in 1895 through most of the first half of the 20th century, radioactive elements such as uranium and thorium used in industry and medicine in the United States were regulated by the states. In the middle of the 20th century the Army Corps of Engineers managed the first large-scale uses of radioactive materials in the Manhattan Project, which produced the world's first nuclear weapons. These activities were kept secret until after World War II.

Weapon component manufacturing along with other uses of materials controlled under the wartime program were first regulated under the Atomic Energy Act of 1946, the McMahon Act. The McMahon Act was intended to ensure the security of nuclear materials rather than to control their radiological hazards. It defined three categories of regulated radioactive material (source, byproduct, and special nuclear) that have been preserved in subsequent revisions of the Act and that are used in other laws and regulations (see Appendix E). The Act also created the Atomic Energy Commission (AEC) to oversee all nuclear activities begun in the Manhattan Project (DOE, 1996).

The material categories and definitions in the McMahon Act were established before the health hazards of nuclear radiation were fully appreciated—nuclear security was the overriding concern. Over the past 60 years, new regulations based on these original definitions developed as a patchwork while knowledge was gained, new materials and technologies discovered, and risks recognized. It is in this context that the Board on Radioactive Waste Management initiated this study and the committee developed its findings for this report.

FEDERAL STATUTES APPLICABLE TO LOW-ACTIVITY WASTES

The Atomic Energy Act of 1954 (AEA) replaced the McMahon Act, ended the government monopoly on use of nuclear materials, and established the framework for the commercial nuclear industry. In 1974, the Energy Reorganization Act disbanded the AEC and established the Nuclear Regulatory Commission (USNRC) to control commercial nuclear activities, and the Energy Research and Development Administration (ERDA) to control defense nuclear activities. The Department of Energy (DOE) replaced ERDA in 1977. The Environmental Protection Agency (EPA) was established in 1970 and has authority under the AEA to set radiation protection criteria and standards and issue radiation protection guidance for federal agencies. EPA also controls radioactive material under authorities granted by other statutes. Statutes that provide authority for the federal regulation of low-activity wastes are listed and described briefly in Sidebar 2.1.

Most low-activity wastes fall under provisions of the AEA because they arose as source, byproduct, or special nuclear materials. Notable exceptions are wastes that contain naturally occurring radioactive materials (NORM) from non-nuclear activities, such as mining, oil and gas production, and water treatment. Wastes that include NORM are federally regulated only if the waste, or the feedstock in processes that produced the waste, contains uranium or thorium in concentrations greater than 0.05 percent by weight (i.e., AEA source material).

Federal statutes define one important group of low-activity wastes—low-level wastes—only by exclusion: low-level waste is not spent nuclear fuel, high-level waste from fuel reprocessing, transuranic waste, or AEA section 11e.(2) byproduct material (waste from processing of uranium or thorium ore). Thus, at this time there is no statutory upper limit or lower limit for the level of radioactivity required to declare a material to be low-level waste.[1] As a result the radioactivity in wastes that meet the definition of low-level waste may be low enough that it is essentially undetectable or high enough to produce acute harm to humans or serious contamination incidents.

FEDERAL REGULATIONS APPLICABLE TO COMMERCIAL LOW-ACTIVITY WASTES

At the federal level, AEA low-activity wastes generated or disposed in the commercial sector are regulated by the USNRC under its authority to license nuclear facilities and the possession of nuclear materials (see Appendix B). The USNRC may relinquish a portion of its authority to individual states, known as Agreement States. All disposal facilities currently licensed to accept low-level wastes are located in Agreement States. The EPA has authority to regulate environmental radiation exposure as well as hazardous chemical wastes, and in certain cases to determine appropriate waste disposal and cleanup methods.

Low-activity wastes that contain both AEA radionuclides and hazardous chemicals are referred to as "mixed wastes" and are thus subject to regulation by both the USNRC and EPA. The Department of Transportation regulates the shipment of radioactive materials while the USNRC has the authority to regulate certain packages for transportation of nuclear materials. Sidebar 2.2 summarizes federal regulations for low-activity wastes in the commercial sector.

Non-AEA wastes, such as TENORM wastes, are subject to EPA radiation protection standards and guidance. The Resource Conservation and Recovery Act (RCRA) provides another important authority for the EPA to regulate non-AEA material. States must go through a formal delegation process to receive EPA authorization to implement the

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[1] Upper limits on the concentrations of radionuclides in low-level waste that can be disposed in near-surface facilities are imposed by the USNRC in 10 CFR Part 61. The USNRC has embarked on a rulemaking for the disposition of solid materials that contain very low levels of radioactivity.

SIDEBAR 2.1 STATUTES RELEVANT TO THE REGULATION AND MANAGEMENT OF LOW-ACTIVITY WASTE

Atomic Energy Act of 1954, As Amended

The purpose of the Atomic Energy Act (AEA) (42 U.S.C. Sect. 2011-Sect. 2259) is to assure the proper management of source, special nuclear, and byproduct material. The AEA and the statutes that amended it delegate the control of nuclear energy primarily to the DOE, USNRC, and EPA. The AEA provides the following definitions:

- source material — (1) uranium, thorium, or any other material that is determined by the USNRC pursuant to the provisions of Section 61 of the AEA to be source material; or (2) ores containing one or more of the foregoing materials, in such concentration as the USNRC may by regulation determine from time to time (AEA, Section 11[z]);
- special nuclear material — (1) plutonium, uranium enriched in the isotope 233 or the isotope 235, and any other material that the USNRC, pursuant to the provisions of Section 51 of the AEA, determines to be special nuclear material, but does not include source material; or (2) any material artificially enriched by any of the foregoing, but does not include source material (AEA, Section 11[aa]); and
- byproduct material — (1) any radioactive material (except special nuclear material) yielded in or made radioactive by exposure to radiation incident to the process of producing or utilizing special nuclear material, and (2) the tailings or wastes produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content (AEA, Section 11[e]).

Byproduct material declared as waste is usually referred to as 11e.(1) or 11e.(2) waste, consistent with the AEA definitions.

The AEA references the Nuclear Waste Policy Act of 1982 (NWPA, see below) for the definition of high-level radioactive waste, spent nuclear fuel, and the exclusionary definition of low-level radioactive waste. A definition of transuranic waste (material contaminated with elements of atomic weight greater than 92) was added to the AEA in 1988.

Reorganization Plan No. 3 (1970)

Although this is not a statute, it was significant in delineating the responsibilities and interactions of the federal agencies.

When the Environmental Protection Agency (EPA) was created, it received certain functions and responsibilities from other federal agencies. Among the functions transferred to EPA was the AEA authority to "establish generally applicable environmental standards for the protection of the general environment from radioactive material. As used herein, standards mean limits on radiation exposures or levels, or concentrations or quantities of radioactive material, in the general environment outside the boundaries of locations under the control of persons possessing or using radioactive material." EPA also received the functions of the Federal Radiation Council, including the responsibility to develop and issue radiation protection guidance to all federal agencies.

Energy Reorganization Act (1974)

The Energy Reorganization Act amended the AEA to split the federal authority over the defense and civilian uses of nuclear materials and facilities. The Atomic Energy Commission was replaced by two new entities. The Nuclear Regulatory Commission (USNRC) became responsible for the regulation of civilian nuclear facilities and activities, and the Energy Research and Development Administration (ERDA) became responsible for defense-related nuclear facilities and activities—including regulation of defense program wastes, and civilian nuclear research and development activities, e.g., advanced reactors.

Department of Energy Organization Act (1977)

The Department of Energy Organization Act created the Department of Energy (DOE) as a cabinet-level agency. DOE replaced ERDA, combined parts of several other agencies, and took over responsibility for defense program wastes.

Nuclear Waste Policy Act of 1982, As Amended

The Nuclear Waste Policy Act (NWPA) provided statutory definitions for the terms "high-level radioactive waste" (HLW) and "spent nuclear fuel." However, the NWPA defined "low-level radioactive waste" (LLW) in terms of what it is not. That is, LLW is defined as material that is not HLW, spent nuclear fuel, transuranic waste, or AEA byproduct material. The NWPA provides authority for the USNRC to classify material as HLW. Waste containing naturally occurring or accelerator-produced radioactive material (i.e., non-AEA-defined nuclear fuel cycle material) is not included in the NWPA.

Uranium Mill Tailings Radiation Control Act of 1978

The Uranium Mill Tailings Radiation Control Act (UMTRCA) addresses the regulation and control of uranium mill tailings (byproduct material as defined in section 11e.(2) of the AEA). UMTRCA vested the EPA with overall responsibility for establishing health and environmental cleanup standards for uranium milling sites and contaminated vicinity properties, the USNRC with responsibility for licensing and regulating uranium production and related activities including decommissioning, and the DOE with responsibility for remediation of inactive mill tailings sites and long-term monitoring of all the decommissioned sites.

Low-Level Radioactive Waste Policy Act of 1980, As Amended in 1985

The Low-Level Radioactive Waste Policy Act (LLRWPA) establishes state (including regional compacts of states) and federal responsibility for the disposal of LLW and defines the roles of federal agencies (particularly the DOE and the USNRC). The LLRWPA also refers to the USNRC classification of LLW in 10 CFR Part 61. The definition of LLW is essentially the same as in the NWPA, although transuranic wastes are not specifically excluded in the 1985 Amendments.

Comprehensive Environmental Response, Compensation, and Liability Act of 1980, As Amended by the Superfund Amendments and Reauthorization Act of 1986

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as Superfund, gives the EPA, in conjunction with state regulators, the authority to investigate and remediate sites placed on the National Priority List. The full process includes site characterization, evaluation of alternative remediation strategies, and public involvement and results in a legal Record of Decision (ROD). Many sites contaminated with radioactive material, including those licensed by USNRC or controlled by DOE, have been placed on the National Priority List. Guidance for cleaning up contaminated soil and materials, including TENORM, have been issued by EPA.

Resource Conservation and Recovery Act of 1976

The Resource Conservation and Recovery Act (RCRA) has been amended several times, with the most significant amendments passed in 1984 as the Hazardous and Solid Waste Amendments. RCRA provides for the cradle-to-grave control of chemically hazardous wastes by imposing management requirements on generators and transporters of hazardous waste and on owners and operators of treatment, storage, and disposal facilities. Regulations pertaining to RCRA waste disposal facilities (landfills) include such details as liner and cover designs.

The RCRA hazardous waste regulations are found in Title 40 of the Code of Federal Regulations. Parts 260 through 265 describe hazardous waste management, provide EPA's lists of hazardous wastes, and set standards that must be met by hazardous waste generators and managers. EPA's land disposal restrictions are given in Part 268 and its permit programs in Part 270.

RCRA specifically excludes material regulated under the AEA from its jurisdiction; however, RCRA is applicable to the hazardous constituents in waste contaminated with both chemically hazardous and radioactive materials, which could include accelerator-produced materials.

RCRA hazardous waste program, but EPA leaves implementation of RCRA solid waste provisions almost entirely to the states.[2] Radiation protection responsibilities may also be delegated to individual states. As noted later in this report, there are significant differences in the states' approaches to regulating low-activity wastes.

In addition to the primary federal regulations summarized in Sidebar 2.2, several other regulations affect the quantity and disposition of low-activity wastes. Materials that cannot be released or that are contaminated in decommissioning or site cleanup work will become waste. For example, the USNRC regulations governing the decommissioning of licensed sites contaminated with residual radioactive material establish a 25 millirem/year dose criterion for the release of a site for restricted or unrestricted use (10 CFR Part 20, Subpart E, Radiological Criteria for License Termination). Similarly the EPA has developed a 15 millirem/year criterion for the cleanup of soils contaminated with radioactive material (OSWER No. 9200.4-18 Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination).

The EPA has exercised its authority under the Clean Air Act to develop standards that limit radon emissions from surface sources (for example, 40 CFR Part 61, Subpart R, National Emission Standards for Radon Emissions from Phosphogypsum Stacks) and subsurface natural geologic deposits on which structures are built, and radioactive emissions from DOE facilities (40 CFR Part 61, Subpart H, National Emission Standards for Emissions of Radionuclides other than Radon from Department of Energy Facilities). The EPA has the authority to regulate non-AEA radioactive waste under the Toxic Substance Control Act (TSCA—15 U.S.C. S/S 2601 et seq. 1976) but has not exercised this authority to date.

[2] Most TENORM wastes are categorized as solid wastes but not as hazardous waste and thus are state-regulated.

SIDEBAR 2.2 FEDERAL REGULATIONS THAT APPLY TO COMMERCIAL SECTOR LOW-ACTIVITY WASTES

10 CFR Part 61, Licensing Requirements for Land Disposal of Radioactive Waste

These USNRC requirements apply to all LLW containing source, special nuclear, or byproduct material that are acceptable for disposal in a near-surface facility. LLW waste is defined the same way as it is defined in the LLRWPA and the NWPA, namely, radioactive waste that is not classified as high-level radioactive waste, transuranic waste, spent nuclear fuel, or byproduct material as defined in section 11e.(2) of the AEA (i.e., uranium or thorium tailings and waste). Part 61.55 defines three LLW classes (A, B, and C) that are acceptable for disposal in near-surface facilities. Greater than Class C (GTCC) low-level radioactive wastes are the responsibility of DOE. The DOE must dispose of GTCC wastes in a deep geologic disposal facility licensed for high-level waste or in some other manner approved by the USNRC. [NOTE: Federal government responsibility for GTCC is not in the regulations, but in the 1985 LLRWPA Amendments.]

10 CFR Part 20, Subpart K, Waste Disposal

This regulation addresses disposal by release into sanitary sewers, treatment or disposal by incineration, and disposal of specific wastes that are below specified activity levels.

10 CFR Part 40, Domestic Licensing of Source Material, Appendix A, Criteria Relating to the Operation of Uranium Mills and the Disposition of Tailings or Wastes Produced by the Extraction of Concentration of Source Material from Ores Processed Primarily for their Source Material Content (Incorporating 40 CFR Part 192, "Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings")

The criteria apply to uranium mill tailings (section 11e.[2] material under the AEA) generated at mill sites licensed in or after 1978, the date of enactment of the Uranium Mill Tailings Radiation Control Act. Under the USNRC's interpretation of UMTRCA, the Commission does not have jurisdiction to regulate mill tailings generated prior to 1978.

40 CFR Part 266, Standards for the Management of Specific Hazardous Wastes and Specific Types of Hazardous Waste Management Facilities

Subpart N of these standards exempts certain mixed waste from RCRA requirements if it satisfies specific criteria.

40 CFR Part 300, National Oil and Hazardous Substances Pollution Plan

This regulation implements CERCLA, including the identification of applicable or relevant and appropriate requirements (ARARS). ARARS are specified on a case-by-case basis in each Record of Decision (ROD). When there is no ARAR, or when the ARAR is considered to be non-protective, a life-time risk range of 10^{-4} to 10^{-6} is used.

2003 Advance Notice of Proposed Rulemaking (anticipated)

The EPA is requesting public comment on methods to define and alternatives for disposal of low-activity radioactive waste, including exemption for mixed wastes containing small amounts of radioactive material for disposal in a RCRA Class C disposal cell.

DEPARTMENT OF ENERGY CONTROL OF LOW-ACTIVITY WASTES

The manufacture of nuclear weapons, which began with the Manhattan Project, is now the responsibility of the DOE—along with responsibility for radioactive waste left as a legacy of the Cold War (DOE, 1996).[3] The DOE is self-regulating for low-level waste (LLW) generated and disposed on its own sites. To determine which wastes are deemed to be LLW, DOE uses the exclusionary definition of LLW provided by the Nuclear Waste Policy Act of 1982 (NWPA), as amended. Accordingly, DOE manages all waste as LLW unless it meets the definition of high-level waste, spent fuel, transuranic waste, or byproduct material (as defined in section 11e.[2] of the AEA, as amended). DOE excludes NORM waste from its definition of LLW, but regulates potential exposures under its radiation protection directives and often manages small amounts of NORM as LLW. LLW that contains hazardous substances as defined by the EPA in 40 CFR Parts 260 and 261 is managed as mixed low-level waste (MLLW).

In addition to promulgating regulatory requirements that have the force of law, e.g., 10 CFR Part 835 (see Sidebar 2.3), DOE has developed a number of Orders addressing radioactive waste and other issues. These DOE Orders do not have the legal enforcement mechanism of a federal regulation. Instead, DOE Orders are incorporated by reference into individual government contracts, and the provisions of the referenced DOE Orders are enforced through contract oversight. This system is complex and tends to vary from contract to contract and over time. To address this issue, DOE embarked on a program of replacing many of its Orders with regulations. However, several years ago DOE abandoned this effort as being too cumbersome.

STATE REGULATIONS

Federal statutes provide three important responsibilities for the states with regard to low-activity wastes: (1) each state must have a way to dispose of its own low-level wastes (but not NORM wastes); (2) states may assume portions of the USNRC's regulatory authority by becoming an Agreement State for the regulation of LLW or uranium mill tailings; and (3) the states regulate non-AEA wastes under authority provided by the state legislature (because they are not covered by federal statutes).

As noted in Sidebar 2.1, the LLRWPA of 1980 required every state to provide for disposal of its own LLW, either alone or in cooperation with other states. The law was intended to encourage the formation of regional interstate compacts, which would be ratified by Congress, for disposing of LLW. In 1985, because no compacts had been ratified or disposal sites selected, Congress amended the LLRWPA to create milestones and incentives for siting disposal facilities (see Sidebar 2.4). Although the milestones have generally been missed (only three disposal sites are operating, as will be discussed in Chapter 3), the states have formed 10 compacts, most states are members of a compact, but no new sites have been developed by the compacts. The compacts and their membership are summarized in Table 2.1.

Section 274 of the AEA, as amended, provides the statutory basis for Agreement States. The USNRC may relinquish to the states portions of its regulatory authority to

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[3] The Department of Defense is responsible for U.S. military operations, including deployment of nuclear weapons.

SIDEBAR 2.3 DOE REGULATIONS AND ORDERS

DOE Order 435.1, Radioactive Waste Management (1999) (together with corresponding Manual (DOE M 435.1-1) and Implementation Guide (DOE G 435.1-1))

DOE Order 435.1 covers all high-level waste, transuranic waste, and low-level waste handled by all elements of DOE, including accelerator-produced waste and the radioactive component of mixed waste. It also covers both byproduct material as defined by section 11e.(2) of the AEA*,* as amended, and naturally occurring radioactive material when the byproduct material or naturally occurring radioactive material are managed at DOE LLW facilities. Order 435.1 does not apply to spent fuel from nuclear reactors. Chapter IV of the manual addresses LLW. DOE does not classify wastes using the USNRC's Class A, B, C system. For DOE, the location of its sites is confined to the location of its facilities, and only DOE generators send waste to them. Thus, DOE individually evaluates the performance capabilities of its sites and establishes waste acceptance criteria for each based on a site-specific assessment.

10 CFR Part 835, Occupational Radiation Protection (1998)

DOE's radiation protection requirements are equivalent to those contained in the requirements for the commercial sector in 10 CFR Part 20 and are contained in two separate directives. The first is 10 CFR Part 835, which addresses occupational radiation protection. It establishes radiation standards, limits, and program requirements for protecting individuals from ionizing radiation resulting from the conduct of DOE activities. Part 835 requires that DOE activities involving occupational radiation exposure "shall" be conducted in compliance with a documented radiation protection program (RPP) as approved by DOE. Effective occupational radiation protection programs ensure that the health and safety of the work force are adequately protected by maintaining individual and collective radiation doses below regulatory limits and by implementing a process that seeks doses that are as low as is reasonably achievable (ALARA). The documented RPP includes the programs, plans, procedures, schedules, and other measures undertaken to ensure worker health and safety through compliance with 10 CFR Part 835. The rule applies to exposures from the management of waste at DOE facilities and contains requirements for controlling property that may be contaminated.

DOE Order 5400.5, Radiation Protection of the Public and the Environment (1990)

DOE Order 5400.5 requires DOE facilities to maintain public doses of radiation below established limits and constraints and as low as practicable below the limits using the ALARA process. The order contains requirements for limiting liquid discharges and air emissions. It includes requirements to limit sewer discharges and use of soil columns for controlling disposed radioactive material. Order 5400.5 also contains DOE's requirements for managing technologically enhanced NORM and 11e.(2) byproduct material and DOE's process for control and release of property from DOE control. Property containing low levels of residual radioactive material may be released for unrestricted (e.g., release for residential use of a property) or in some cases, restricted use (e.g., disposition of waste or other personal property to a RCRA landfill or release of real property for recreational use only) if the levels are shown to be below DOE-approved authorized limits. Property demonstrated to meet surface activity guidelines may be released for unrestricted use. Alternatively, unrestricted release or restricted release may be done to authorized or supplemental limits developed and approved (by DOE) on a case-by-case basis if they meet dose constraints and ALARA process requirements.

license and regulate byproduct materials, source materials, and certain quantities of special nuclear materials. The mechanism for the transfer of USNRC's authority to a state is an agreement signed by the governor of the state and the chairman of the Commission.

In order for an Agreement State to license a low-level waste disposal facility, the state regulations for low-level waste disposal must be compatible with USNRC's regulations in 10 CFR Part 61. The USNRC also conducts periodic reviews of Agreement State programs, as part of its Integrated Materials Performance Evaluation Program, to determine if the state's regulations and practices continue to be adequate and compatible with USNRC's. If requested, USNRC provides assistance to the Agreement States on low-level radioactive waste disposal issues. Presently there are 33 Agreement States, including the three states that currently have licensed LLW disposal facilities. Several other states are in the process of reaching agreement with USNRC.

There are differences among the states as to what materials are regulated as TENORM and how they are regulated. While a few states have begun to establish a licensing system for all industries that generate TENORM wastes (similar to the way the USNRC licenses facilities that handle radioactive sources), others control this class of wastes using specific regulations for TENORM. The majority treat the waste in accordance with general radiation protection requirements. The environmental, radiation protection, and waste disposal methods in most cases are based on EPA and or USNRC regulations or guidance.[4]

TABLE 2.1 Interstate Compacts for Low-Level Waste Disposal

Compact Name	Associated States
Northwest	Alaska, Hawaii, Idaho, Montana, Oregon, Utah, Washington, Wyoming
Southwestern	Arizona, California, North Dakota, South Dakota
Rocky Mountain	Colorado, New Mexico, Nevada
Midwest	Indiana, Iowa, Minnesota, Missouri, Ohio, Wisconsin
Central	Arkansas, Kansas, Louisiana, Nebraska, Oklahoma
Texas	Maine, Texas, Vermont
Central Midwest	Illinois, Kentucky
Appalachian	Delaware, Maryland, Pennsylvania, West Virginia
Atlantic	Connecticut, New Jersey, South Carolina
Southeast	Alabama, Florida, Georgia, Mississippi, Tennessee, Virginia
Unaffiliated States	District of Columbia, Massachusetts, Michigan, New Hampshire, New York , Puerto Rico, Rhode Island, North Carolina

SOURCE: USNRC, 2002.

[4] The NORM Technology Connection maintained by the Interstate Oil and Gas Compact Commission (IOGCC) provides state-specific regulatory requirements applicable to NORM-containing waste <http://www.iogcc.state.ok.us/norm/reg/state>.

An effort has been undertaken by the Conference of Radiation Control Program Directors (CRCPD) to develop a model TENORM regulation that could be adopted or modified by state agencies for use in their particular state. The model regulation[5] (Suggested State Regulations for Control of Radiation—Part N) would require licensing of companies which possesses, use, manufacture, or make products or wastes in which the radium-226 content is ≥ 5 picocuries/gram. As of this writing, the model regulation has been redrafted a number of times. Once the draft regulation is approved by the CRCPD board of directors, it will be provided to several federal agencies (including EPA, USNRC, and DOE) for their comments and concurrence. If approved, the regulation would be published for states to consider in developing their own approaches to TENORM.

SIDEBAR 2.4 EFFECTS OF THE LOW-LEVEL RADIOACTIVE WASTE POLICY ACT

In 1980, Congress enacted the Low-Level Radioactive Waste Policy Act, reflecting its declared policy of holding each state responsible for providing capacity for disposal of its low-level radioactive waste either within its own boundaries or through state compacts. However, Congress provided no penalties if states failed to provide disposal capacity. Five years later, there were still no assured disposal locations for such waste for at least thirty states.

In response to this failure of the majority of states to designate disposal sites within their respective borders or to enter into regional compacts, Congress again addressed this disposal issue in the Low-Level Waste Policy Amendments Act of 1985. To stimulate the states into action, Congress provided three types of incentives. The first was to provide those states that did enter into regional compacts with monetary incentives. The second was to allow states hosting disposal sites to impose substantial surcharges for waste disposal on those states that failed to comply, and, after 1990, to deny non-compliant states access to disposal facilities. The third incentive provided that if a state was unable to provide for disposal of its waste by 1996, then the state could be required to take title of the waste from the waste generator and take possession of the waste. In addition, the state would be liable for any damages incurred by the waste generator resulting from the failure of the state to take the waste.

In 1990, the State of New York filed suit claiming that the 1985 amendments were in violation of various provisions of the Constitution. Although the State of New York initially lost the case, U.S. Supreme Court agreed to hear the State's case on appeal and ultimately ruled in favor of the State on some of the issues raised (*State of New York v. United States*, 488 U.S. 1041 (1992)).

The Court noted that although Congress may encourage, or provide incentives for, states to regulate in a particular way, it could not coerce a state into action. The Court went on to find the first and second incentives provided in the 1985 amendments to be permissible under the Constitution. However, the Court also found the third incentive to be constitutionally prohibited coercion in which Congress attempted to compel the states to regulate low-level waste disposal. Thus, the Court struck down the third incentive, while allowing the other two to remain intact to encourage state action.

The Court concluded that although the third incentive was prohibited, Congress nevertheless might have many other methods of achieving its goal of regional self-sufficiency in low-level radioactive waste disposal. However, in more than a decade since the Court's ruling, Congress has not revisited this issue.

[5] See <http://crcpd.org/SSRCRs/TOC_8-2001.htm>.

EVOLUTION OF THE RISK CONCEPT FOR CONTROLLING LOW-ACTIVITY WASTES

Risk does not explicitly appear in current statutes or regulations that control LAW; rather risk is an evolving concept that is receiving increased attention by policy makers, regulators, and members of the public. This section provides a brief history of the concept's initial development from radiation dose-based regulations. In its final report the committee will address the concept of risk and options for using risk to better inform future regulatory policies for low-activity wastes.

As noted earlier in this chapter, the Atomic Energy Act of 1946 (McMahon Act) was intended to ensure security of nuclear materials rather than to control their hazards to workers or the public. The earliest controls for releases of radioactive materials from licensed activities, in air or water effluents, were set by the AEC in 10 CFR Part 20. These control levels for individual radioisotopes were set with the idea of controlling the exposure of the persons closest to the site, based on directly measurable effluents at the site boundary for liquid effluents or the point of release for gaseous effluents.

International principles for radiation protection were adopted as part of applying the effluent limits, including the ALARA principle. This principle is followed when radioactive releases are not only controlled to strict limits, but are also controlled so that releases, or exposures, are "as low as reasonably achievable" (ALARA). The ALARA principle was applied to effluent control, e.g., to nuclear reactor gaseous effluents through 10 CFR Part 50, Appendix I (1975).

Years later, when the EPA developed new emission limits for radionuclides under the Clean Air Act (NESHAPS), 40 CFR Part 61, they were based directly on 10^{-4} (one chance in 10,000) lifetime risk of cancer death, corresponding to an exposure of about 10 mrem/yr to the maximally exposed individual. In retrospect, the EPA concluded that the USNRC programs for fuel cycle facilities, including 10 CFR Part 50, Appendix I, for reactors, provided adequate risk protection and amended the NESHAPS accordingly.[6]

In the early 1980s the USNRC developed an environmental impact statement (EIS) for a typical shallow land disposal site for LLW (NUREG-0945, Final Environmental Impact Statement on 10 CFR Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste," USNRC November 1982). In this EIS the requirements for licensing LLW disposal were developed by analyzing the potential releases from a large burial site containing typical amounts of various forms of LLW, given imposition of the licensing requirements being considered. The measure of impact was not risk directly, but radiation dose to persons near the site boundary, analyzed to occur at any time far

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[6] EPA's policy is to apply a consistent risk management approach to all of its programs and statutory mandates. CERCLA regulations call for cleanups to achieve a residual lifetime risk of between 1 in 1,000,000 [10^{-6}] and 1 in 10,000 [10^{-4}] (40 CFR 300.430(e)(2)(i)(A)(2)). When applied to radiation, EPA considers a dose of 15 mrem/yr over a lifetime to correlate to a risk of approximately 3×10^{-4} (3 in 10,000), which is considered "essentially equivalent" to the 1×10^{-4} target (OSWER directive 9200.4-18, August 22, 1997).

Following the CERCLA approach, EPA explicitly considers risk implications in other actions involving radiation. In 1989, EPA established airborne emission limits for a wide variety of source categories under the Clean Air Act (NESHAPs), 40 CFR Part 61. EPA's approach to establishing limits required first that an "acceptable risk" level be established with a presumptive limit on maximum individual risk of approximately 1 in 10,000.

into the future. This same dose-basis analysis has been adopted by DOE in the Order 435.1 guidance.

3
Low-Activity Waste Overview

This chapter summarizes current low-activity radioactive waste (LAW) management and regulatory practices in the United States. The first section provides information on the characteristics, inventories, and regulatory controls for wastes in each of the categories introduced in Chapter 1. The second section provides a perspective on the radiological hazards of these wastes. The final section describes currently available disposal sites and disposal practices, with more detailed descriptions given in Appendix D. In developing this chapter the committee has focused on the relevant information that led to its findings, rather than reproducing the detailed summary information available elsewhere.[1]

Among the wastes described in this chapter, low-level wastes (LLW) from Department of Energy (DOE) and commercial nuclear facilities have received the most attention from regulators and the public.[2] LLW in the form of debris, rubble, and contaminated soils from facility decommissioning and site cleanup constitute much larger volumes than LLW from operational facilities but generally contain very low concentrations of radioactive material. Discrete radioactive sources that are no longer useful also meet the definition of LLW even though they may contain highly concentrated radioactive material. Although similar in their characteristics, DOE "defense" LLW and commercial LLW are generally managed and regulated separately according to their respective origins in the DOE or private sector.

Tailings and other wastes from mining and processing uranium and thorium ores have been produced in very large quantities. Like LLW, uranium and thorium wastes are subject to the Atomic Energy Act (AEA), but concern about them has been limited mainly to populations living around mining and milling sites—including Native Americans. Non-nuclear enterprises such as mineral recovery and water treatment produce equally large or larger volumes of wastes that contain the same naturally occurring radio-

[1] Detailed summary information is available from DOE, 1999, 2001, 2003, the Manifest Information Management System (MIMS) at <http://mims.apps.em.doe.gov>, and the Central Internet Database (CID) <http://cid.em.doe.gov>. Note that DOE 1999, 2003, and MIMS provide commercial-sector data.

[2] Low-level wastes fall under the Atomic Energy Act. They are defined in the Nuclear Waste Policy Act of 1982 by exclusion, namely waste that is not spent fuel, high-level waste from fuel reprocessing, transuranic waste, or 11e.(2) byproduct material (see Chapter 2).

active materials (NORM) as uranium and thorium wastes. NORM wastes are not subject to the AEA, and there is no consistent system for regulating them.

COMMERCIAL LOW-LEVEL WASTE

Commercial LLW comes from nuclear power facilities and other industrial, medical, and research applications. Typical examples include protective shoe coverings and clothing, mops, rags, equipment and tools, laboratory apparatus, process equipment, reactor water treatment residues, non-fuel-bearing hardware, and some decontamination and decommissioning wastes. Low-level radioactive wastes are produced in essentially every state. With a few exceptions, the radionuclides contained in commercial LLW are relatively short-lived fission products.

The 1978 revision of the AEA gave the Nuclear Regulatory Commission (USNRC) authority to regulate wastes from the private sector. Defense LLW becomes subject to USNRC regulations if it is shipped for disposal in a commercial facility. In its regulations governing the disposal of commercial low-level waste, the USNRC defines three classes (A—the least hazardous—B, and C) based largely on the concentrations and half-lives of radionuclides in the waste. High or essentially unrestricted concentrations of radionuclides with half-lives less than 5 years are allowed, concentrations of some specific fission and activation products with longer half-lives are restricted, and concentrations of transuranic nuclides with half-lives greater than 5 years are limited to 100 nanocuries/gram (see Appendix B, Tables B.1 and B.2). The vast majority of the volume of commercial low-level waste consists of the least hazardous USNRC Class A waste.

The Manifest Information Management System (MIMS) provides information on waste shipments to commercial disposal facilities (Barnwell, South Carolina; Clive, Utah; and Richland, Washington, discussed later in this chapter).[3] According to MIMS, approximately 600,000 cubic meters of waste containing almost 9 million curies of radioactivity were disposed from 1989 through 2001 (see Figures 3.1 and 3.2). The vast majority of the waste, some 85 percent of the volume and the curies, came from nuclear utilities. Wastes from other industries amounted to about 7 percent of the volume and the curies. Wastes received from DOE sites made up most of the remainder. Waste from medical and academic origins amounted to less than 1 percent of the volumes and curies disposed.

The trend toward volume reduction begun in the mid 1990s resulted from significant efforts to reduce waste production and to further reduce volume by compaction and super compaction of waste. The substantial volume increase beginning in 2000 is the result of large amounts of slightly contaminated soils, debris, and rubble that Envirocare of Utah began receiving in that year. The waste sent to Envirocare, however, contained less that 1 percent of the curies disposed.

[3] See <http://mims.apps.em.doe.gov>. DOE does not assure the quality of this information.

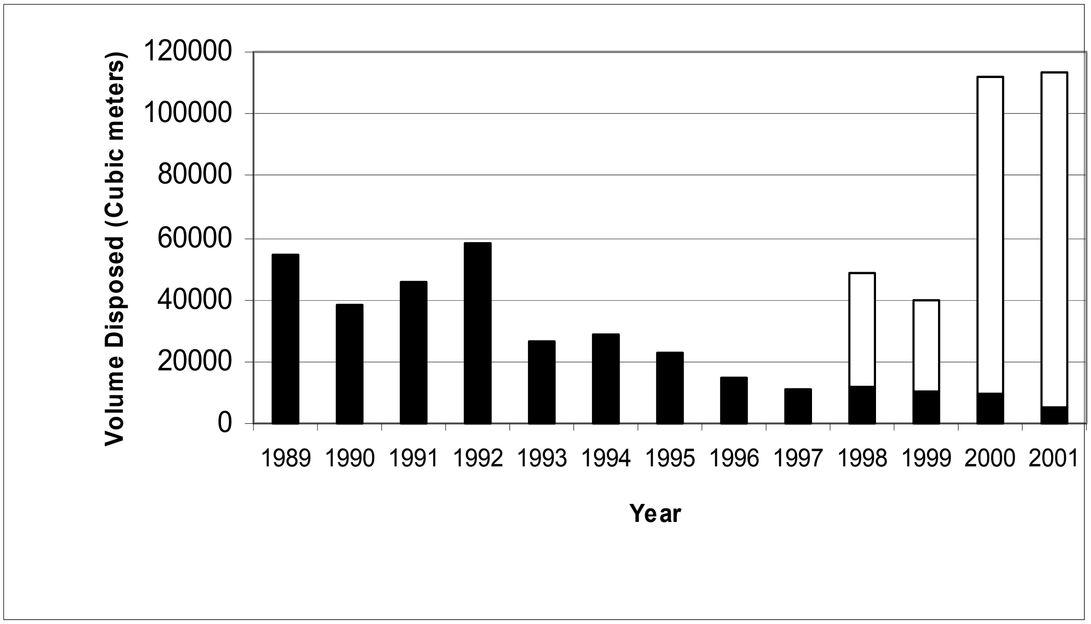

Figure 3.1. Volumes of Low-Level Waste Disposed at Commercial Sites. Upper bars beginning in 1998 are very-low-level wastes received at Envirocare of Utah.
Source: MIMS, 20003.

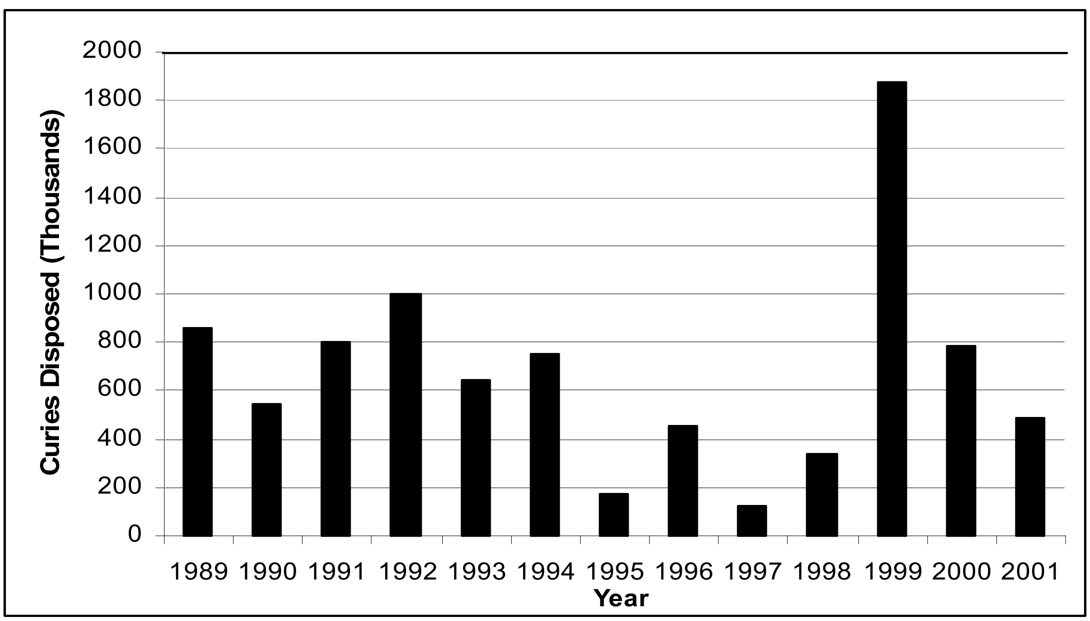

Figure 3.2 Curies of Low-Level Waste Disposed at Commercial Sites.
Source: MIMS, 20003.

DOE DEFENSE LOW-LEVEL WASTE

Defense LLW has been generated in the course of producing or using special nuclear materials throughout the DOE complex, including fuel fabrication, reactor operation, and isotope separation and enrichment, and it continues to be produced in site cleanup work.[4] In general terms, DOE LLW is quite similar to commercial LLW except that some radionuclides specific to nuclear fuel reprocessing appear in higher quantities. For example, some DOE LLW contains transuranic isotopes, mainly plutonium, at concentrations between 10 and 100 nanocuries per gram (nCi/g).

Cumulatively through fiscal year (FY) 1999, DOE had disposed an estimated total volume of 5.8 million cubic meters of low-level waste and contaminated media containing almost 50 million curies. In FY-2000, DOE treated about 833,000 cubic meters of LLW and disposed about 40,000 cubic meters. DOE disposed of another 29,000 cubic meters in commercial facilities. The treated and subsequently disposed waste volumes were about equal to new additions, so the beginning and year-end inventory remained almost constant at about 146,000 cubic meters. DOE estimates that another 2 million cubic meters will be disposed by 2070 (DOE, 2001; CID, 2003). DOE's main sites that generate and dispose of LLW are shown in Figure 3.3.

As noted in Chapter 2, DOE is self-regulating for wastes generated and disposed at its sites. Onsite wastes that do not fit into other waste categories defined by Order 435.1 are managed and disposed as LLW. DOE LLW shipped to commercial facilities is subject to the USNRC's or the Agreement State's commercial waste regulations.

SLIGHTLY RADIOACTIVE SOLID MATERIALS

Nuclear facility decommissioning produces debris, rubble, and contaminated soil characterized by large volumes of materials having small quantities of radioactive contamination—including concrete, plastics, metals and other building materials, equipment, and packaging. A previous study (NRC, 2002a) introduced the term "slightly radioactive solid materials" (SRSM) to describe these materials. These wastes are produced in both the DOE and commercial sectors.

Decommissioning the existing commercial power reactor facilities may generate up to about 8 million cubic meters of SRSM, about 90 percent being concrete. These same facilities may also yield about a million metric tons of metallic SRSM (NRC, 2002a). DOE estimates that about 700 of its reactor and processing facilities will be fully decommissioned in the course of site cleanup (NRC, 1998). DOE also estimates that about 821,000 cubic meters of solid contaminated media may be excavated during its site cleanup activities between 2000 and 2010 (DOE, 2001).

Currently these wastes are regulated and disposed as USNRC Class A wastes, which means they must be disposed in USNRC licensed facilities (or their equivalent at DOE sites). However, these wastes usually contain very small amounts of radioactivity. Debris and rubble sent to Envirocare amounted to about 90 percent of the total LLW volume disposed in 2000, but amounted to only about 1 percent of the radioactivity (MIMS, 2003). The USNRC and its Agreement States have allowed alternative disposal

[4] Department of Defense low-activity waste is not discussed in this report. This waste is managed and disposed by contractors as commercial waste regulated by the USNRC unless it is classified for security purposes. Classified waste is managed and disposed by DOE.

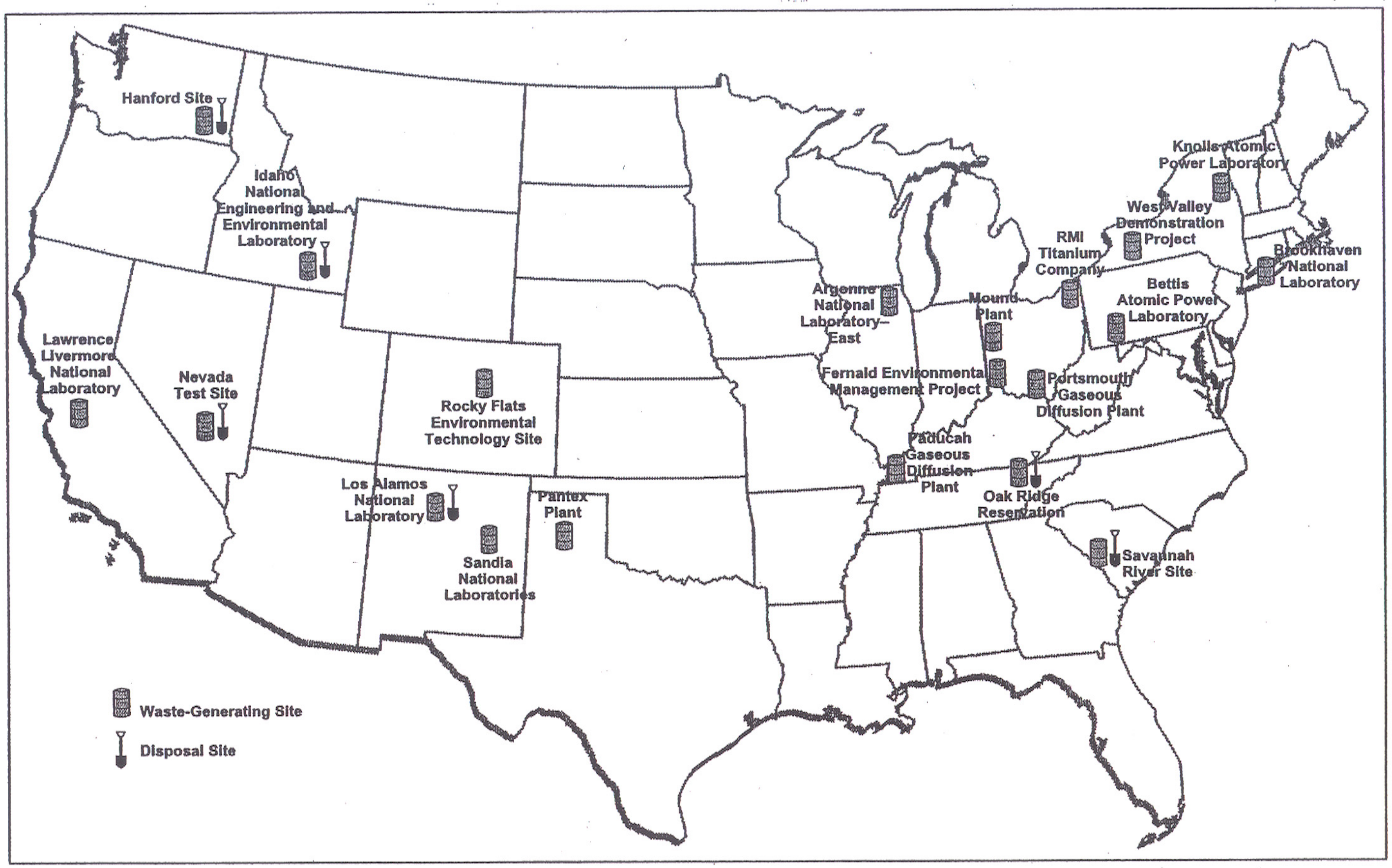

Figure 3.3 DOE's Major Low-Level Waste Generating Sites and Disposal Facilities
SOURCE: GAO, 2000.

pathways (e.g., in permitted landfills) on a case-by-case basis (USNRC, 2002). Both the Environmental Protection Agency (EPA) and USNRC are investigating alternative disposition options for these wastes.

DISCRETE RADIATION SOURCES

Discrete radiation sources usually consist of a radioactive material in a leak-tight metal casing. The amount and type of radioactive material used (e.g., Co-60, Sr-90, Cs-137, Ir-192, Cf-252, Am-241) determine the type and intensity of emitted radiation. Sealed sources have essential uses in medical diagnostics and therapy, industry (radiography, well logging), and research. Over the course of time, radioactive decay may reduce their intensity below a useful level, or the application may become obsolete—such as the use of Ra-226 in medicine or Cs-137 irradiators. Unused radioactive sources are often referred to as "spent" sealed sources although they may continue to present a significant radiation hazard if not properly stored or disposed (IAEA, 2001).

Sealed sources in commercial use are licensed by the USNRC or an Agreement State. DOE controls sealed sources used at its sites. As a practical matter, however, the identifying marks and records on many sealed sources, especially older sources, are sometimes lost and the sources themselves may become lost or "orphaned." According to some estimates there are over 30,000 orphan sources in the United States. In cooperation with the Conference of Radiation Control Program Directors (CRCPD), the EPA, USNRC, and DOE are funding a program to assist states to retrieve and securely dispose of orphan sources.[5]

While many discrete sources clearly are not low-activity materials, they meet the Nuclear Waste Policy Act definition of LLW (see Chapter 2). Their designation as LLW generally works in practice because the radionuclides in these sources typically have half-lives of a few decades or less,[6] and their small volume allows them to be safely stored in shielded containers. Regulatory authorities in most countries allow their disposal in near-surface facilities designed for LLW. Nonetheless, these sources represent the opposite extreme from the large volumes and low activities that characterize most other wastes considered in this report.

URANIUM MINING AND PROCESSING WASTES

Beginning with the Manhattan Project in 1942, uranium and thorium ores were mined and processed on a massive industrial scale (DOE, 1996). Initial ore production was dedicated to the manufacture of material for nuclear weapons; subsequent production supported the nuclear power industry as well. From the earliest days of the weapons program into the Cold War period, the government and its contractors, while maintaining the urgent pace of the program, developed an irregular pattern of waste retention and storage. The residues from recovering and processing uranium and thorium were stored in outdoor

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[5] See <http://www.epa.gov/radiation/cleanmetals/orphan.htm> and <http://www.crcpd.org/PDF/Announcement.pdf>.

[6] Radium-226 and Americium-241 are notable exceptions with half-lives of about 1600 and 460 years, respectively.

piles for later management or sometimes buried on site. In some cases tailings have been used inappropriately as construction materials (NRC, 1986).

The radiological hazards of these wastes arise from decay of naturally occurring uranium and thorium isotopes and their daughter isotopes (see Table 3.1). Beginning with Th-232, U-238, or U-235, radioactive decay produces a series of other radioisotopes (daughters) leading to the eventual formation of stable (non-radioactive) isotopes. The half-lives of the thorium and uranium parent isotopes are extremely long—comparable to the age of the Earth, which is why they still exist in nature. The radioactivity associated with wastes containing these isotopes is therefore low but persistent. Radon-222, a daughter product of U-238 is of particular concern because it is gaseous and can diffuse from tailings piles unless they are properly capped.

Uranium and thorium processing tailings wastes are defined as byproduct material in section 11e.(2) of the AEA (see Chapter 2). Typical tailings piles range in size from tens of thousands to over three million cubic meters (DOE, 2003). If these wastes were generated at facilities under license by the USNRC in 1978 or thereafter, they are managed under the Uranium Mill Tailings Radiation Control Act (UMTRCA) of 1978. Both the EPA and the USNRC regulate aspects of UMTRCA site remediation and waste disposal.

The USNRC has determined that it does not have authority to regulate uranium mining and processing wastes at facilities that were not under USNRC license at the time of passage of UMTRCA. Some of these wastes, generated between the start of the Manhattan Project and 1978 and related to the nation's early atomic weapons program, are managed under the Formerly Used Sites Remediation Action Program (FUSRAP) established under the AEA. FUSRAP cleanups are conducted by the Army Corps of Engineers (see Sidebar 3.1). The DOE manages uranium-contaminated wastes on its sites.

TABLE 3.1 Uranium, Thorium, and Their Longer-Lived Radioactive Decay Products

Isotope	Half-life	Isotope	Half-life	Isotope	Half-life
U-238	4.47×10^9 y	U-235	7.04×10^8 y	Th-232	1.41×10^{10} y
Th-234	24.1 d	Pa-231	3.28×10^4 y	Ra-228	5.75 y
U-234	2.46×10^5 y	Ac-227	21.77 y	Th-228	1.91 y
Th-230	7.54×10^4 y	Ra-223	11.44 d	Pb-208	stable
Ra-226	1600 y	Pb-207	stable		
Rn-222	3.82 d				
Pb-210	22.3 y				
Po-210	138.4 d				
Pb-206	stable				

Note: y = years; d = days
SOURCE: NRC, 1999a

SIDEBAR 3.1 FUSRAP and UMTRCA: TWO PROGRAMS FOR THE SAME MATERIALS

The Formerly Utilized Sites Remedial Action Program (FUSRAP) is an environmental program established in March 1974 by the Atomic Energy Commission under the authority of the Atomic Energy Act of 1954. The program was created to identify, investigate, and take appropriate cleanup action at sites with radioactive contamination resulting from the nation's early atomic weapons program. Cleanup at FUSRAP sites primarily involves building debris and soils contaminated with uranium and thorium.

The Department of Energy (DOE) assumed responsibility for FUSRAP in 1977. Initially records were reviewed and surveys were performed on more than 400 sites connected with the atomic weapons program. The DOE began limited cleanups of some sites in 1979 and started major remedial actions in 1981; cleanup of 25 sites was completed by 1997.

Congress transferred responsibility for the administration and execution of FUSRAP to the Army Corps of Engineers as part of the Energy and Water Development Appropriations Act of 1998. While the Corps was assigned the responsibility for the 21 sites in the program at the time of the transfer, the DOE continues to determine the eligibility of new sites for the program. The Corps conducts cleanups under the framework of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), as amended.

The Uranium Mill Tailings Radiation Control Act (UMTRCA) controls uranium- and thorium-contaminated wastes produced after 1978. Title I of UMTRCA deals with DOE remedial action programs at former mill tailings sites, and Title II deals with non-DOE mill tailings sites and uranium mining sites that are licensed by the USNRC or an Agreement State according to USNRC regulations (see Table 2.1 in Chapter 2 for details on UMTRCA).

With FUSRAP and UMTRCA, wastes with similar radiological hazards arising mostly from uranium, thorium, and their radioactive decay products fall into different regulatory and management boxes depending on whether the materials were generated at facilities that were under license by the USNRC at the time of passage of UMTRCA in 1978. This statutory construct has led to a novel approach to managing pre-1978 ore processing residuals within FUSRAP. If the USNRC approves materials from a FUSRAP site as alternate feed material to be processed at a uranium mill for further extraction of uranium, albeit uneconomically, the residues fall under UMTRCA (because they arose after 1978) and can be put in the mill's tailings pile after processing. Some refer to this as "sham processing," an act to reclassify the waste for disposal—although from a technical standpoint the FUSRAP waste may in fact be the same as the tailings waste and the USNRC has ruled that economics is not a factor in approving alternate feed material. However, if the FUSRAP waste (or other material) is not 11e.(2) in the clear sense of the AEA, then there are significant administrative hurdles in the way of direct disposal of this material into the tailings impoundment of an UMTRCA facility.

NORM AND TENORM WASTES

Naturally occurring radioactive materials (NORM) arise in many mineral extraction operations and are often discarded as wastes—examples include phosphate industry residues, scale and sludge from oil and gas production, non-uranium mining tailings, and coal ash residues (see Table 3.2). The materials are referred to as technologically

TABLE 3.2 Domestic Processes that Generate NORM Waste

Process	Waste description	Radionuclide concentration (picocuries per gram)	Estimated waste generation (million metric tons per year)	Major generator locations
Soils in the United States	(Benchmark for typical background)	0.2 – 4.2		
Coal combustion	Fly ash	2 – 9.7	44	Midwestern and South Atlantic states
	Bottom ash and slag	1.6 – 7.7	17	
Geothermal energy production	Solids	10 – 250	0.05	California
Metal mining and processing	Slag, leachate and tailings from:			Mostly Midwestern and Western states
	-Large volume industries*	0.7 – 83	1000	
	-Special application metals	3.9 – 45	0.47	
	-Rare earth metals	5.7 – 3,200	0.002	
Municipal waste treatment	Sludge**	1.3 – 11,600 (picocuries per liter)	3	All, especially North Central and Atlantic Coastal Plain
Oil and natural gas production	Scale and sludge	Background to over 100,000	2.6	States where petroleum or natural gas is produced or processed
Phosphate mining and fertilizer production***	Ore tailings and phosphogypsum (calcium sulfate	7 – 55	48	Florida, Idaho, and other states in the West and Southeast

* Such as iron and copper mining.
**Filters typically have concentrations of 40,000 picocuries/gram but arise in much smaller volumes.
***Phosphate fertilizer volumes are about one order of magnitude less, with the same concentrations of radionuclides.

SOURCES: DOE, 1997, and <http://www.tenorm.com>.

enhanced NORM, or TENORM if their concentrations of radioactive materials are increased above naturally occurring levels. Sludge or filter media from water and wastewater treatment are good examples of TENORM waste. Estimates of the NORM and TENORM inventories from U.S. industries exceed 60 billion tons (NRC, 1999a).

The radionuclides in NORM waste arise mainly from uranium and thorium series isotopes (see Table 3.1). NORM waste is therefore radiologically similar to uranium mining and milling wastes, although some radioisotope concentrations may differ. Unlike uranium and thorium wastes, NORM is not a byproduct of the production of fissionable materials and is not controlled by the AEA. Except for Department of Transportation regulations on transportation of radioactive materials, for the most part NORM is not regulated by federal agencies but rather by states.[7]

As noted in Chapter 2, there is considerable variation among states, which often regulate non-AEA materials collectively as "NARM" (see Sidebar 3.2). In Agreement States the same state agencies that have authority for AEA materials usually regulate NORM materials as well. States that regulate NORM specify concentrations of radium below which materials are exempt from regulation as waste, but the concentrations vary from state to state. Recognizing these disparities, the Conference of Radiation Control Program Directors has developed suggested state regulations for TENORM.[8]

HAZARD CONSIDERATIONS FOR LOW-ACTIVITY WASTE

The radiological hazards of LAW depend on both its level of radioactivity and its longevity. As noted by the Board on Radioactive Waste Management at the outset of this study (see Chapter 1), the radiological hazard of LAW is typically much less than that for spent nuclear fuel or high-level reprocessing waste, but the hazard may persist for very long periods. Chapter 4 will summarize the committee's view of these risks and where they fall within the current regulatory scheme. While the regulatory system was developed primarily to control radiological risks of LAW—the focus of this report—non-radiological hazards are also important.

The radioactivity in any material depends on the concentration of radioactive atoms present and their half-lives (see Sidebar 3.3). Low-activity wastes are often only slightly contaminated so the radioactivity is very low. However, LAW may contain a substantial concentration of radionuclides with very long half-lives (e.g., uranium and thorium wastes, NORM wastes). The radioactivity is low, but the hazard does not diminish appreciably with time. In addition, DOE and USNRC regulations allow some wastes with relatively high radioactivity to be managed and disposed as LLW. These wastes contain fission or activation products with relatively short half-lives so their radioactivity diminishes rather rapidly—over time scales of decades to centuries.

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[7] If sites containing NORM are listed on the National Priorities List they are subject to CERCLA, and the management of the NORM wastes generated at the site are governed by applicable or relevant and appropriate requirements (ARARS), which are specified on a case-by-case basis in each Record of Decision (ROD). When there is no ARAR or when the ARAR is considered to be non-protective, a lifetime risk range of 10^{-4} to 10^{-6} is used to establish the standard.

[8] See <http://www.crcpd.org/SSRCRs/N_4-99.PDF>.

SIDEBAR 3.2 NARM, NORM, and TENORM

These acronyms refer to an assortment of materials that are not subject to federal regulation under the AEA, and thus are regulated by the individual states. In many state regulations and elsewhere (e.g., NCRP, 2002) they are referred to collectively as NARM (naturally occurring and accelerator-produced radioactive materials).

Particle accelerators are often used to produce isotopes for medical and research purposes. In addition to these products, components of the accelerator itself may become radioactive. According to the EPA there are no firm estimates of the amount of accelerator-produced wastes, but it is generally accepted that the volume of these wastes containing isotopes with half-lives greater than one year (i.e., long enough to present waste management challenges) is very small compared to other low-activity wastes. The committee paid little attention to these materials. For completeness, however, concentrated materials with longer half-lives, e.g., Co-60, Ir-192, can be included as discrete sources in the committee's categorization of low-activity waste. Otherwise the waste will be radiologically similar to defense or commercial low-level waste.

Naturally occurring radioactive materials (NORM) are a subset of NARM. They contain radioactive elements such as uranium and thorium, which were present when the Earth was formed, their radioactive decay products,* and some isotopes that are produced by cosmic rays from the sun—such as C-14. In its categorization the committee chose to distinguish wastes in which NORM is coincidental to recovery of mineral resources (mining, oil, gas) from wastes produced in recovery of uranium and thorium for nuclear purposes. Uranium and thorium mining and processing wastes are covered by the AEA.

Most mineral recovery operations tend to concentrate NORM to produce TENORM—technologically enhanced NORM. Examples are pipe scale, tailings piles, sludges, and filters. Water purification and treatment also produce TENORM. While noting that EPA and state regulations generally address TENORM only; for completeness the committee included both NORM and TENORM together in one category.

***** Radium-226, a radioactive decay product of U-238 (see Table 3.1), was formerly used as a radiation source for medical treatments and also as a luminous paint for instrumentation. Radium effects among workers helped lead to recognition of radiation hazards. Radium wastes are no longer considered a serious issue in the United States.

Low-activity radioactive wastes that contain chemically hazardous substances are subject to regulations of the EPA under the Resource Conservation and Recovery Act (RCRA) and other statutes described in Chapter 2. For these "mixed wastes," regulations of the DOE, USNRC, or Agreement States control the radioactive constituents, and EPA regulations or state permits control the chemical constituents. Chemical hazards and their regulation are described in other reports (NCRP, 2002; NRC, 1999a,b, 2002c). EPA regulations on the chemical components of mixed wastes are generally prescriptive: The Agency defines certain materials as hazardous, specifies treatment standards to be met prior to disposal, and specifies standards for construction and operation of hazardous waste sites. Institutional control, rather than site performance criteria, ensures that disposed waste remains safe.

Shipments of LAW, including NORM, are controlled by the Department of Transportation. Transportation hazards are not as well recognized as chemical hazards for LAW. Present requirements placed on waste generators along with the limited number of disposal sites result in transporting large amounts of LAW over long distances.

Envirocare of Utah receives very large amounts of slightly contaminated wastes shipped by rail and truck from all parts of the country. Plans are underway to ship the San Onofre, California, reactor pressure vessel to Barnwell, South Carolina—possibly by sea around South America because the vessel and shipping cask are too large for cross-country rail shipment and too heavy to go through the Panama Canal (St. Onge, 2003). Barnwell is the only disposal facility that can accept Class B or C waste from California (see the following section on disposal).

SIDEBAR 3.3 RADIOACTIVITY IN LOW-ACTIVITY WASTES

The radioactivity in any material is proportional to the concentration of radioactive atoms of a given type divided by their half-life:

$$A = k\,N / t_{1/2}$$

where A is the number of radioactive disintegrations in a given time—typically disintegrations per second (becquerels) or a much larger unit (curies), equal to about 3.7×10^{10} becquerels; N is the number of radioactive atoms of a given kind (radionuclides) often expressed in units of concentration (e.g., per unit mass or volume of waste); $t_{1/2}$ is the time required for half of the initial number of radionuclides to decay (half-life); and k is a constant equal to about 0.7.

Wastes are usually contaminated with more than one radionuclide, so the total radioactivity is the sum of their individual radioactivities. The radioactivity in wastes is typically measured or calculated on the basis of volume (e.g., becquerels per cubic meter).

For slightly contaminated wastes (protective clothing, building debris, rubble) the number—or concentration—of radioactive atoms, N, is relatively small so the activity, A, is small, according to the above equation. Conversely, wastes may contain relatively large concentrations of radionuclides with long half-lives (uranium residues, NORM). For these wastes the quotient ($N / t_{1/2}$) is small and the radioactivity, A, is still low—but it persists for a very long time.

LOW-ACTIVITY WASTE DISPOSAL

DOE practices onsite treatment and disposal for much of the LAW generated at its major sites, which are depicted in Figure 3.3. Disposal capacity at DOE sites, especially at the Nevada Test Site and Hanford, Washington, appears to be more than adequate for future disposal needs (GAO, 2000). Nevertheless, DOE does make use of commercial treatment and disposal capabilities (described below), when appropriate for cost reduction or to supplement DOE's capabilities.

In the commercial sector, there are three sites available for disposal of low-activity wastes: Barnwell, South Carolina, operated by Chem-Nuclear; Clive, Utah, operated by Envirocare of Utah; and within the DOE Hanford site near Richland, Washington, operated by U.S. Ecology. A fourth facility at Grand View, Idaho, operated by U.S. Ecology and designed for chemically hazardous wastes, is currently receiving FUSRAP waste. Each of these facilities is limited in the types and volumes of waste that can be disposed. Sidebar 3.4 summarizes commercial waste disposal regulations and practices. Appendix D provides descriptions of the disposal facilities.

Only one disposal facility, at Barnwell, is currently accepting USNRC Class A, B, and C low-level waste from all states. South Carolina formed the Atlantic Compact (formerly the Northeast Compact) with Connecticut and New Jersey on July 1, 2000. Under the Compact, South Carolina can limit the use of the Barnwell facility to the three compact members. A state law enacted in June 2000 phases out acceptance of non-compact waste after 2008.

The other existing disposal facility for all three major classes of low-level waste is the Hanford, Washington, site operated by U.S. Ecology. Controlled by the Northwest Compact, the Hanford site will continue taking waste from the neighboring Rocky Mountain Compact (see Table 2.1) under a contract.

The Envirocare of Utah facility is available for most Class A wastes generated nationwide. The site's operator, Envirocare, applied to the state on November 1, 1999, for a license amendment to accept Class B and C waste as well. Utah regulators granted the license amendment. For the amendment to take effect, however, approvals by the state legislature and the governor are required. Envirocare has deferred seeking final state approval in part because of citizens' concerns and considerable political sensitivity to waste disposal issues (e.g., a proposed commercial spent fuel storage facility near Envirocare on the Goshute reservation).

It is notable that no new commercial disposal facilities have been opened since the Envirocare of Utah site opened in 1988. After the Low-Level Waste Policy Act made states responsible for disposal of their low-level wastes and directed the formation of interstate compacts, the states and compacts spent about $600 million in mostly failed siting efforts (GAO, 1999, also see Sidebar 2.1). A site at Ward Valley, California, was licensed by U.S. Ecology in 1993, but land transfer issues from the federal to state government effectively blocked that site's startup. Recently, however, the Texas legislature and governor have approved bills to allow commercial low-level waste disposal in that state.

Although the specific reasons for the lack of success vary among compacts and states, there are several common threads. One thread is the controversial nature of nuclear waste disposal, which often manifests itself in the form of skepticism about and opposition to disposal facilities by members of the public and political leaders. Waste generators, compacts, and states have in recent years reassessed their need for disposal facilities and deferred the development of facilities because of the declining volume of Class B and C wastes, the high cost of developing new disposal facilities, and the continued availability of disposal services to most waste generators (GAO, 1999).

Current policies (specifically, surcharges and taxes levied by states that host the three commercial disposal facilities) put into place in the 1980s for managing commercial low-level radioactive waste have led to higher prices to generators. Potential lack of access to existing disposal capacity due to restrictions by host states creates concerns among generators, especially in view of the planned closing of the Barnwell site to users outside the Atlantic Compact in 2008. The picture for defense low-level waste, much of which is radiologically similar to the civilian waste stream, is very different with access to disposal capacity being assured at a much lower cost (DOE, 2002).

SIDEBAR 3.4 REGULATION AND DISPOSAL OF LLW IN NEAR-SURFACE FACILITIES

The USNRC and the states govern the siting, operation, and closure of all low-level waste disposal facilities. The USNRC has set forth requirements to protect people from releases from the site, prevent inadvertent intrusion into the waste, protect workers during operation, and ensure the stability of the site after closure.

USNRC regulations for required low-level waste disposal time periods. The USNRC requires that Class A low-level waste be contained for up to 100 years, Class B waste for 300 years, and Class C waste for up to 500 years.

USNRC regulations for low-level waste disposal facilities. The USNRC has established technical requirements for shallow land disposal. These requirements include areas, such as wildlife preserves, to be avoided; the site must be sufficiently isolated from groundwater and surface water; and the site must not be in an area of geological activity (such as volcanoes or earthquakes). Regardless of design, all low-level waste disposal sites use a series of natural and engineered barriers to prevent radioactivity from reaching the environment. There are five designs for building disposal facilities: shallow land burial, modular concrete canister, below-ground vault, above-ground vault, and earth-mounded concrete bunker.

Waste Treatment. Most LLW including those wastes that are LAW as defined in this report are disposed in 55-gallon drums, B-25 boxes, or other specialized concrete, metal, or sometimes wooden containers. Wastes are prepared by compaction, super compaction, dewatering solidification, consolidation, or other techniques approved by regulators of disposal sites. These requirements are spelled out in site licenses and waste acceptance plans or waste acceptance criteria.

Shallow land burial. Waste containers are placed in long, lined trenches 25 or more feet deep. The trenches are covered with a clay cap or other low-permeability cover, gravel drainage layers, and a topsoil layer. They then are contoured and replanted with vegetation for drainage and erosion control. In addition, an intrusion barrier, like a thick concrete slab, is added to Class C waste trenches. The sites are carefully monitored to ensure performance in compliance with the regulations. Facilities are sited in an area away from surface water and where travel of any groundwater is slow.

Other disposal systems include but are not limited to:

Modular concrete canister disposal. This method consists of individual waste containers placed within concrete canisters, which are then disposed in shallow land sites. The array of canisters has an earthen cover. This additional engineered barrier system has been used at the Barnwell, South Carolina, facility since 1995 and has been proposed for Classes B and C disposal at Envirocare.

Below-ground vault. This type of disposal uses a sealed structure built of masonry blocks, fabricated metal, concrete, or other materials that provide a barrier to prevent waste migration. It has a drainage channel, a clay top layer and a concrete roof to keep water out, a porous backfill, and a drainage pad for the concrete vault.

Above-ground vault or engineered berm. This is a reinforced-concrete building that provides isolation on the Earth's surface. Its walls and roof are two to three feet thick, and it has a sloping roof to aid water runoff. Some Canadian utilities use similar above-ground vaults for storing low-level waste for later disposal. For low-activity radioactive waste, above-ground engineered berms provide the same isolation as shallow land burial. Envirocare of Utah uses above-ground engineered berms.

SOURCE: NEI <http://www.nei.org/index.asp?catnum=2&catid=73>.

4
Issues and Findings

As described in Chapters 2 and 3, low-activity wastes are regulated primarily on the basis of their origin (national defense, nuclear power, resource recovery) under a patchwork of federal and state statutes put into place over a period of almost six decades. The current system for regulating this waste lacks overall consistency and, as a consequence, waste streams having similar physical, chemical, and radiological characteristics may be regulated by different authorities and managed in disparate ways. These disparities have health, safety, and cost implications, and they may undermine public confidence in regulatory agencies.

Table 4.1 summarizes the committee's overview of the radiological hazards associated with low-activity waste and the current regulations that address the hazards. The first three waste categories shown on the table (low-level waste; slightly radioactive solid materials; and discrete radioactive sources) are governed by section 11e.(1) of the Atomic Energy Act (AEA). They meet the Nuclear Waste Policy Act's exclusionary definition of low-level waste (LLW) (see Chapter 2). In the commercial sector, waste is regulated by the Nuclear Regulatory Commission (USNRC) under 10 CFR Part 61. At Department of Energy (DOE) sites the same types of waste are controlled by DOE Order 435.1.

Radiological hazards in these first three waste categories vary greatly, however, and these differences are not adequately recognized by the broad statutory definitions of LLW. Even the USNRC's classification system for LLW (e.g., USNRC Classes A, B, and C) does not completely address these differences. At the low end, radioactivity in the very large volumes of debris, rubble, and soil is so low it is often difficult to measure. Recognizing this, the USNRC has initiated a rulemaking on alternative dispositions for "slightly radioactive solid materials." Both the EPA and USNRC are considering allowing the use of hazardous waste landfills for these materials.[1] At the opposite extreme, discrete sources declared as waste are often extremely radioactive and have the potential to produce acute radiation effects and serious contamination incidents. The larger sources exceed USNRC Class C limits on near-surface disposal, and in the absence of a geological repository (e.g., Yucca Mountain if licensed and constructed) have no present means of disposal.

The radiological hazards in the last two waste categories in Table 4.1, uranium and thorium processing wastes and naturally occurring radioactive materials (NORM)

[1] Landfills for chemically hazardous wastes must meet design and permitting requirements of the EPA, under authority of the Resource Conservation and Recovery Act (RCRA). States can set standards for acceptance of radioactive materials in RCRA landfills when the state has jurisdiction.

wastes, arise from the uranium and thorium and their daughter isotopes. While their concentrations and isotopic distributions may vary, their hazards are roughly comparable. Nevertheless, their regulatory frameworks differ greatly. Uranium and thorium wastes fall under the AEA section 11e.(2) definition of byproduct materials. If the facilities that contained these wastes were under license by the USNRC at the time of the passage of the Uranium Mill Tailings Radiation Control Act (UMTRCA) in 1978, their wastes are managed according to the provisions of UMTRCA. Otherwise they may be managed under the Formerly Utilized Sites Remedial Action Program (FUSRAP).

Since ore residuals managed under FUSRAP were generated prior to the enactment of UMTRCA, the USNRC has determined that it does not have the authority to regulate them; such materials are not prohibited by federal law from disposal in RCRA-permitted landfills. UMTRCA wastes must be disposed in USNRC-licensed facilities. Disposal of pre-1978 ore residuals managed under FUSRAP or other programs can be regulated by the states. NORM and technologically enhanced NORM (TENORM) wastes are also regulated by the states, because they are not included in the AEA and therefore not subject to federal regulation. Among the states, NORM, TENORM, and FUSRAP wastes are not regulated consistently.

FUSRAP wastes provide a good example of political and regulatory inconsistencies. The Army Corps of Engineers is currently shipping railcar loads of FUSRAP wastes from St. Louis, Missouri, to the U.S. Ecology facility in Grandview, Idaho, which is permitted by the state for hazardous chemical wastes and radioactive materials not regulated by the USNRC. Previous FUSRAP disposals in the state-permitted Buttonwillow, California, hazardous waste landfill encountered severe opposition (see Sidebar 4.1). Another option used by the Corps is disposal at Envirocare of Utah according to that site's USNRC license for AEA 11e.(2) byproduct waste. DOE has disposed of about 1.5 million cubic meters of waste, which is mostly the same as the St. Louis FUSRAP wastes, at Weldon Springs, Missouri. This DOE facility was not an available option for the Corps.

Relative to AEA waste, NORM waste has received little attention from policy makers or the public. Sidebar 4.2 describes a situation in which NORM wastes, generally accepted for disposal at a Michigan landfill, are actually more radioactive than highly regulated LLW from the nuclear industry. In presentations to the committee, the EPA, USNRC, and the Conference of Radiation Control Program Directors (CRCPD) clearly expressed the need for recognizing and more consistently controlling the radiological hazards of NORM wastes.

TABLE 4.1 Summary of low-activity waste Hazards and Regulations

Category	Radiological Hazard	Governing Statutes/Regulation(s)
Low-level wastes from commercial and defense activities	Mostly short-lived (half- lives on the order of decades) fission and activation products. Some (e.g., reactor components, filters) have high specific activity and penetrating radiation. Potential short-term hazards to workers and long-term hazards to the environment if the wastes are allowed to migrate	DOE: AEA, 11e.(1), self-regulated under DOE Order 435.1 COMMERCIAL: AEA, 11e.(1), USNRC or state regulated --10CFR61 Classes A, B, and C per Part 61.55 --Greater-than-Class C is responsibility of DOE to receive and dispose of with USNRC approval.
Slightly radioactive solid materials (debris, rubble, and contaminated soil from facility decommissioning and cleanup)	Mostly short-lived (half-lives on the order of decades) fission and activation products in large volumes of steel, concrete, other construction materials, and soils. Low hazards to workers but potential long-term hazards to the environment if the wastes are allowed to migrate.	
Discrete radioactive sources declared as waste	Mostly short-lived (half-lives on the order of decades) fission products of high specific activity. Potential short-term hazards to individuals and to the environment if the sources should make their way into metal recycle facilities or if they are allowed to migrate from waste disposal facilities.	
Uranium and thorium ore processing wastes	Very long-lived parent and daughter isotopes. Low specific alpha activity and little penetrating radiation. Low hazards to workers, but potential long-term hazards to the environment if the radionuclides are allowed to migrate, in particular radon gas and its daughters, which constitute an inhalation hazard.	Defense waste, pre-1978: not directly regulated Defense waste, post-1978: --UMTRCA, Title I --10CFR40, Appendix A --small quantities, under DOE Order 435.1 Commercial waste, post-1978: --UMTRCA Title II --10CFR40, Appendix A
Naturally occurring and technologically enhanced naturally occurring radioactive materials (NORM and TENORM wastes).	Very long-lived parent and daughter isotopes. Low specific alpha activity and little penetrating radiation. Low hazards to workers, but potential long-term hazards to the environment if the radionuclides are allowed to migrate, in particular radon gas and its daughters, which constitute an inhalation hazard.	DOE: DOE Order 435.1 --DOE M435.1-1, IV B.(3) covers accelerator-produced waste --DOE M435.1-1, IV B.(4) covers 11e.(2) and NORM Other: States have authority --CRCPD has recommended Part N for specific regulations.

SIDEBAR 4.1 ARMY CORPS OF ENGINEERS FUSRAP ISSUES

The U.S. Army Corps of Engineers is responsible for remediating 21 sites that contain 1-2 million cubic meters mainly of uranium-contaminated soils and debris. The USNRC does not license or otherwise regulate:

- pre-1978 ore processing residuals at facilities that were not under license by the USNRC in 1978 or thereafter, or
- residuals of ores processed for other than their source material content (i.e., non-AEA section 11e.(2) material).

While the Corps believes the USNRC's legal position is correct, the position is questionable from a health, safety, and environmental perspective. Standards of individual states that control the residuals vary considerably. The above-listed residuals are radiologically and chemically similar and present similar or identical hazards to 11e.(2) byproducts, which are controlled by the USNRC. The radiological similarity between 11e.(2) byproducts and pre-1978 residuals has led some to reject the USNRC determination that the pre-1978 residuals do not come under material regulated by the USNRC and are not low-level radioactive waste.

The Corps has disposed of building rubble contaminated with pre-1978 residuals at the Buttonwillow, California, hazardous waste disposal facility. This practice was criticized in the belief that the materials should only be disposed in a USNRC licensed facility.

> "When I learned that the Corps had disposed of 2,200 tons of radioactive waste in an *unlicensed* hazardous waste facility..., I was shocked."

Senator Barbara Boxer, Transcript, Hearing of the Senate Environment and Public Works Committee, July 25, 2000 [emphasis added—the facility was *permitted* to receive these materials, but not licensed].

FINDINGS

In general, the committee believes that there is adequate statutory and institutional authority to ensure safe management of low-activity wastes, but the current patchwork of regulations is complex and inconsistent—which has led to instances of inefficient management practices and perhaps in some cases increased risk overall. Existing authorities have not been exercised consistently for some wastes. The system is likely to grow less efficient if the patchwork approach to regulation continues in the future.

Finding 1

Current statutes and regulations for low-activity radioactive wastes provide adequate authority for protection of workers and the public.

In its fact-finding meetings, site visits, and review of relevant literature, the committee found no instances where the legal and regulatory authority of federal and state agencies was inadequate to protect human health. This finding is consistent with that of previous studies by the National Academies and the National Council on Radiation Protection and Measurements (NCRP) described in Chapter 1 (NCRP, 2002; NRC,

SIDEBAR 4.2 NUCLEAR POWER WASTE VERSUS NORM

The Big Rock Point (BRP) nuclear power plant, located in northern Michigan is in the midst of decommissioning. In 2001, BRP officials approached the USNRC, seeking approval for disposing of large quantities of concrete rubble from the decommissioning project in a municipal landfill in northern Michigan.

They proposed a waste characterization and monitoring protocol that would assure that no concrete rubble would go to the landfill if any appreciable quantity of radioactivity were present. All surfaces would be scanned for contamination at predetermined release limits. Any contamination would be removed. Then, the concrete would be rubbleized and bulk scanned. A 5 picocurie above background per gram of rubble cut-off value for approving or rejecting a particular load would be established. The USNRC approved the proposal under the authority of 10 CFR section 20.2002, which gives USNRC the authority to approve disposal for LLW other than in a licensed LLW facility. The plan also was approved by the Michigan Department of Environmental Quality

The BRP personnel worked closely with the landfill owner and the township board in the rural community where the landfill is located, to assure all that the disposal of their decommissioning waste would be fully protective of the environment and the public. . In general, BRP efforts were fairly successful in assuaging public concerns, though some reluctance to taking nuclear power plant waste remains in the minds of some local community residents and township board members. Michigan Department of Environmental Quality representatives had pointed out that there are other things going into the landfill that contain more radioactive material than the rubble. In fact, the coal ash that is used as daily cover for the cells show radioactive material concentrations in the range of 13 picocuries of radium per gram of ash.

Recently, the landfill operator installed portal monitors at the landfill, in preparation for accepting the decommissioning rubble. However, the portal monitor alarm has been tripped when certain loads of oil- and gas-production sludges and coal ash have been brought to the landfill. This material has been coming to the landfill for years, without any recognition of its radiological content. The landfill operator is developing operational procedures for determining when to refuse a load, which has tripped the portal alarm. The Michigan Low-Level Waste Authority has requested, and the landfill operator has agreed, to keep a log of all shipments that trip the portal alarms, to develop a better sense of radioactive materials entering the landfill.
(Source: Michigan Department of Environmental Quality)

1999a, 2002a). Some states, however, have chosen not to exercise regulatory authority over NORM and TENORM wastes. The USNRC has determined not to regulate certain pre-1978 uranium and thorium wastes. The EPA has so far not exercised its authority under the Toxic Substance Control Act to regulate non-AEA radioactive wastes. In addition, some wastes have not been adequately controlled in spite of the existence of regulatory authority. The EPA estimates that some 30,000 “orphan” sealed radioactive sources have disappeared from regulatory control, and notes that since 1983 there have been 26 recorded meltings of sources that were inadvertently mixed with scrap steel.[2] These incidents have been expensive, led to very conservative practices in the steel and nuclear in-

[2] The Orphan Sources Initiative is described at <http://www.epa.gov/radiation/cleanmetals/orphan.htm>.

dustries, and fueled public distrust in the regulatory system (HPS, 2002; NRC, 2002a; Turner, 2003).

Finding 2

The current system of managing and regulating low-activity waste is complex. It was developed under a patchwork system that has evolved based on the origins of low-activity waste.

In its information-gathering the committee received a clear message from agencies responsible for managing and regulating low-activity waste: A more consistent, simpler, performance-based and risk-informed approach to regulation is needed (see Sidebar 4.3). Many committee members had difficulty in understanding the regulations well enough to discuss the system and its applications, as noted in Chapter 1. Similarly, the NCRP found that the current waste classification systems "are not transparent or defensible" and that the "classification systems are becoming increasingly complex as additional waste streams are incorporated into the system" (NCRP, 2002, p. 65).

SIDEBAR 4.3 COMMENTS FROM REGULATORS AND MANAGERS

Radiation is radiation. Make decisions based on the radiation in the material and not based on the regulatory box of the material. **Southeast Compact Commission**

DOE would benefit from a more uniform approach to waste management, particularly when DOE uses commercial treatment and disposal. **Department of Energy**

Suggest improvements in management and oversight activities to achieve the greatest risk reductions with available resources. **Environmental Protection Agency**

Consistent, national standards for classifying radioactive materials such as pre-1978 ore processing residuals, oil and gas drilling wastes, and other NORM or TENORM, independent of pedigree... **Army Corps of Engineers**

Address more consistent and harmonized regulation of like materials that fall under different regulatory regimes; identify and address opportunities for more risk informed disposal of low-activity wastes. **Nuclear Regulatory Commission**

These comments were made by sponsors of this study at the first committee meeting (see Appendix A).

Findings 3 and 4

Certain categories of low-activity waste have not received consistent regulatory oversight and management.

Current regulations for low-activity waste are not based on a systematic consideration of risks.

Regulations focused on the wastes' origins have led to inconsistencies relative to their likely radiological risks. Naturally occurring and technologically enhanced naturally occurring radioactive material (NORM and TENORM) are not regulated by federal agencies because they do not fall under the Atomic Energy Act. State regulation of these wastes is not consistent. Nevertheless, these wastes may have significant concentrations of radioactive materials compared to some highly regulated waste streams. For example, NORM wastes routinely accepted at a landfill triggered a radiation monitor intended to ensure that rubble from a decommissioned nuclear reactor meets very strict limits on its radioactivity (see Sidebar 4.2).

Uranium mining and processing wastes, which are radiologically similar to NORM wastes, are regulated under federal authority by their status at the time UMTRCA was enacted. There are no federal regulations that prohibit ore processing residuals at facilities that were not under license by the USNRC in 1978 or thereafter from being disposed in hazardous waste facilities, but mill tailings regulated by the USNRC under UMTRCA, which may be radiologically identical to pre-1978 residuals, are prohibited from being disposed in such facilities. The disposal of FUSRAP waste in a hazardous waste facility in California has been the subject of much recent discussion in Congress, the media, and the regulatory community.

In addition to inconsistencies in regulating the radiological risks, current low-activity waste regulations generally overlook trade-offs between radiological and non-radiological risks. Hundred-thousand-cubic-yard volumes of slightly contaminated soil and debris and very heavy reactor components are being transported long distances for disposal. In developing current requirements for how low-activity wastes are managed or disposed, worker risks in excavating, loading, and unloading large-volume wastes; risks of transportation accidents; and environmental risks and costs (e.g., consuming large amounts of fossil fuel) have not been analyzed and compared in a systematic way to radiological risks.

PUBLIC CONCERNS REGARDING LOW-ACTIVITY WASTE: AN ISSUE FOR THE FINAL REPORT

On beginning this study, the committee was aware that there is persistent and widespread public concern with all aspects of radioactive waste management and disposal (NRC 1996, 2001a, 2002a, 2003; GAO, 1999; Dunlap et al., 1993). During the committee's open sessions, members of the attending public expressed considerable lack of trust in the low-activity waste regulatory system due to its complexity, inflexibility,

and inconsistency. These factors have apparently raised doubts about the system's capability for protecting public health. The key concerns raised in the open sessions—distrust of regulatory institutions and processes, the complexity of the problem, apprehension about risks, and the desire for greater stakeholder and public involvement—is consistent with a large and growing literature on public views of radioactive wastes and how to manage them (DOE, 1993; Dunlap et al., 1993; Slovic, 1993; Rosa and Clarke, 1999; Cvetkovich et al., 2002; Mohanty and Sagar, 2002; NRC, 2003).

The task of this interim report was to develop an overview of current regulatory and management practices for low-activity waste, and thus set the stage for the committee's final report, which will assess policy and technical options for improving the current practices. The assessments will include risk-informed options, and the committee strongly believes that issues of public trust and risk perception will be important considerations in the final report.

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Appendix A
Committee Information-Gathering Meetings

Washington, D.C., December 4-5, 2002

The Nuclear Regulatory Commission's regulation of low-activity wastes and expectations for this study, Scott Flanders, USNRC

The Department of Energy's regulation of low-activity wastes and expectations for this study, Karen Guevara, DOE

The Southeast Compact Commission's role in managing low-activity wastes and expectations for this study, Mike Mobley, SECC

The Army Corps of Engineers' role in managing low-activity wastes and expectations for this study, Tomiann McDaniel and John MacEvoy, USACE

The Environmental Protection Agency's regulation of low-activity wastes and expectations for this study, Adam Klinger, EPA

Public comments

Richland, Washington, February 6-7, 2003

Introduction and overview of the DOE Hanford's low-level waste burial grounds, Rudy Guercia, DOE-Richland

Hanford Environmental restoration disposal facility (ERDF), Owen Robertson, DOE-Richland

Views of the Hanford Advisory Board, Ken Bracken, HAB

Roundtable discussion led by David Leroy, Committee Chairman

Public comments

Hanford Site Visit

U.S. Ecology briefing and site tour, Mike Ault, U.S. Ecology

ERDF briefing and site tour, Rudy Guercia, DOE-RL

200 West Area low-level waste burial site tour, Rudy Guercia, DOE-RL

Salt Lake City, Utah, April 16-17, 2003

Comments from the Tooele County Commissioners, Gene White, Commissioner

Comments from the Utah Department of Environmental Quality, Bill Sinclair, Division of Radiation Control

International Uranium Corporation: Overview and waste issues, Dave Frydenlund, IUC

National Mining Association perspective, Tony Thompson, NMA (by telephone)

Public comments

Envirocare of Utah site visit

Overview and discussion, Ken Alkema, Envirocare of Utah

Bus tour of the site, Gene Perry, Envirocare of Utah

Washington, D.C., June 11-13, 2003

Risk-based classification of radioactive and hazardous chemical wastes—NCRP 139, Allen Croff, Oak Ridge National Laboratory

Perspectives from the Conference of Radiation Control Program Directors on medical waste and NORM, Jill Lipoti, New Jersey Department of Environmental Protection

Increasing disposal options for low-activity and mixed wastes, Adam Klinger, EPA

Disposition of slightly radioactive solid materials, Frank Cardile, USNRC

Milestones and millstones: Industry experience with low-activity waste disposals, Paul Genoa, Nuclear Energy Institute. Comments by Alan Pasternak, CalRad Forum (by telephone)

Roundtable discussion: Framing recommendations for changes in regulatory policy, Frank Marcinowski, EPA; Lawrence Kokajko, USNRC; Karen Guevara, DOE; Kathryn Haynes, SECC

Perspectives on low-activity waste issues, Diane D'Arrigo, Nuclear Information and Resource Service; Judith Johnsrud, Sierra Club

Public comments

Appendix B
U.S. Nuclear Regulatory Commission

The U.S. Nuclear Regulatory Commission (USNRC) is an independent regulatory agency established by the Congress under the Energy Reorganization Act of 1974 to ensure adequate protection of the public health and safety and the environment and to promote the common defense and security in the civilian use of nuclear materials. The USNRC scope of responsibility includes regulation of:

- Commercial nuclear power; non-power research, test, and training reactors;
- Non-DOE fuel cycle facilities; medical, academic, and industrial uses of nuclear materials; and
- Transport, storage, and disposal of nuclear materials and waste.

The regulatory system established by the USNRC has its authority in legislation listed in Chapter 2, Table 2.1. To fulfill this agency's Congressionally mandated mission, the USNRC has established licensing procedures for regulating the use of byproduct, source, and special nuclear materials. Specifically, the goals for radioactive waste management are to: ensure treatment, storage, and disposal of waste produced by civilian use of nuclear materials in ways that do not adversely affect future generations; and to protect the environment in connection with civilian use of source, byproduct, or special nuclear materials through the implementation of the AEA and NEPA.

Current Nuclear Regulatory Commission (NRC 10 CFR Part 20) Regulations define Source Materials, Byproduct Materials, and Special Nuclear Materials as follows:

Source material means:

(1) Uranium or thorium or any combination of uranium and thorium in any physical or chemical form; or

(2) Ores that contain, by weight, one-twentieth of 1 percent (0.05 percent), or more, of uranium, thorium, or any combination of uranium and thorium. Source material does not include special nuclear material.

Byproduct material means:

(1) Any radioactive material (except special nuclear material) yielded in, or made radioactive by, exposure to the radiation incident to the process of producing or utilizing special nuclear material; and

(2) The tailings or wastes produced by the extraction or concentration of uranium or thorium from ore processed primarily for its source material content, including discrete surface wastes resulting from uranium solution extraction processes. Underground ore bodies depleted by these solution extraction operations do not constitute "byproduct material" within this definition.

Special nuclear material means:

(1) Plutonium, uranium enriched in the isotope 233 or in the isotope 235, and any other material that the Commission, pursuant to the provisions of section 51 of the Act, determines to be special nuclear material, but does not include source material; or

(2) Any material artificially enriched by any of the foregoing but does not include source material (10 CR 20.1003).

The USNRC conducts licensing and inspection activities associated with domestic nuclear fuel cycle facilities, uses of nuclear materials, transport of nuclear materials, management and disposal of LLW and HLW, and decontamination and decommissioning of facilities and sites. USNRC also is responsible for establishing the technical basis for regulations, and provides information and technical basis for developing acceptance criteria for licensing reviews.

An important aspect of the USNRC regulatory program is its inspection and enforcement activities. The USNRC has four regional offices (Region I in King of Prussia, Pennsylvania; Region II in Atlanta, Georgia; Region III in Lisle, Illinois; and Region IV in Arlington, Texas), that conduct inspections of licensed facilities including nuclear waste facilities. USNRC also has an Office of State and Tribal Programs, which establishes and maintains communication with state and local governments and Tribes, and administers the Agreement States Program.

An Agreement State is a state that has signed an agreement with the USNRC allowing the state to regulate the use of radioactive material within that state, consistent with the USNRC regulations. Out of the 50 states, 33 are Agreement States.

USNRC issues guidance on how to implement its regulations in the form of Regulatory Guides and Staff Positions. The USNRC staff develops Regulatory Guides to establish a standard approach to licensing. They are not intended to be regulatory requirements, but they do reflect methods, procedures, or actions that would be considered acceptable by the staff for implementing specific parts of USNRC regulations.

Regulatory Guides describe the standard format and content for license applications. Staff Positions are divided into two general types: so-called "generic" positions, dealing with issues which relate to licensing activities for nuclear facilities independent of the technology or site selected; and site-specific positions, which give site guidance or advice applicable to a specific site.

In addition to the guidance, the USNRC staff uses Standard Review Plans (typically, a "NUREG" document), which provide guidance to the USNRC staff in reviewing licensee submittals. These plans are made public so that licensees and applicants understand what is needed to comply with regulations. In this respect, the licensees and applicants have this third type of guidance to assist them in preparing their demonstration of compliance with the applicable regulations and standards.

Important guidance for radiation protection programs is provided in International Commission on Radiation Protection (ICRP) and the National Council on Radiation Protection and Measurements (NCRP) technical guidelines. Applicable recommendations are cited in USNRC staff documents, which focus on dose assessments.

USNRC regulations that affect the management of low-activity waste include the Low-Level Waste Disposal Regulations (10 CFR Part 61), Radiation Protection Standards (10 CFR Part 20), and criteria related to the disposition of uranium mill tailings (10 CFR Part 40, Appendix A). The USNRC regulates the radioactive characteristics of low-level waste materials acceptable for near-surface land disposal through a combination of prescriptive and performance-based requirements. Performance assessment is required to calculate worker and public exposure risks associated with waste disposal. According to the USNRC, a near-surface disposal facility is one in which radioactive waste is disposed within the upper 30 meters of the land surface. Institutional control of access is required for 100 years, and within 500 years radioactivity must decay to a sufficiently low-level so that it will not pose unacceptable hazards to an intruder or the general public.

To meet this latter requirement, further prescriptive regulations define three classes of waste that are deemed suitable for near-surface disposal. Classification as Class A (the easiest to dispose), Class B, or Class C depends on which radionuclides are present and their concentrations (see Tables B.1 and B.2). If the waste qualifies as TRU or is contaminated above certain limits with long-lived radionuclides, it is not suitable for near-surface disposal.[1]

TABLE B.1 Near-Surface Disposal for Allowable Concentrations of Long-Lived Radionuclides

Radionuclide	Concentration, curies per cubic meter (Ci/m^3)
C-14	8
C-14 in activated metal	80
Ni-59 in activated metal	220
Nb-94 in activated metal	0.2
Tc-99	3
I-129	0.08
	Concentration, nanocuries per gram (nCi/g)
Alpha emitting transuranic nuclides with half-life greater than 5 years	100
Pu-241	3,500
Cm-242	20,000

SOURCE: Code of Federal Regulations, Title 10, Part 61.55.

[1] Mining industry waste is excluded from this requirement.

TABLE B.2 Allowable Concentrations of Short-Lived Radionuclides for Near-Surface Disposal

Radionuclide	Class A Waste (Ci/m^3)	Class B Waste (Ci/m^3)	Class C Waste (Ci/m^3)
Total of all nuclides with less than 5-year half-life	700	*a*	*a*
H-3	40	*a*	*a*
Co-60	700	*a*	*a*
Ni-63	3.5	70	700
Ni-63 in activated metal	35	700	700
Sr-90	0.04	150	7,000
Cs-137	1	44	4,600

a: There are no limits for these radionuclides in Class B or C wastes. Practical considerations such as the effects of external radiation and internal heat generation on transportation, handling, and disposal limit the concentrations for these wastes.

NOTE: Not all Class C-or-less wastes will be acceptable at all sites and some GTCC wastes may be acceptable at certain sites. This distinction is the essence of the difference between waste classification and site-specific decisions on remediation.

SOURCE: Code of Federal Regulations, Title 10, Part 61.55.

Appendix C
The Environmental Protection Agency

More than a dozen major statutes or laws form the legal basis for the programs of the Environmental Protection Agency (EPA). EPA authority to develop radiation protection standards and to regulate radioactive materials, including TENORM, is derived from a number of those federal laws, plus Executive Orders.

The authority to develop Federal guidance for radiation protection was originally given to the Federal Radiation Council (FRC) by Executive Order 10381 in 1959 as an offshoot of authorities of the Atomic Energy Act (42 U.S.C. 2011 et seq.) (1954). Over the next decade the FRC developed Federal guidance ranging from guidance for exposure of the general public to estimates of fallout from nuclear weapons testing. Federal guidance developed by the FRC provided the basis for most regulation of radiation exposure by Federal and state agencies prior to the establishment of the EPA.

In 1970, the responsibility for developing Federal guidance for radiation protection was transferred from the FRC to the newly formed EPA under Reorganization Plan No. 3. Federal Guidance Documents are signed by the President and issued by EPA. By signing these, the President provides a framework for Federal and state agencies to develop regulations that ensure the public is protected from the harmful effects of ionizing radiation. Federal Guidance is also an opportunity for the President to promote national consistency in radiation protection regulations. For example, the guidance document "Radiation Protection Guidance to Federal Agencies for Occupational Exposure," issued by EPA in 52 CFR 2822, January 27, 1987, established general principles and specifies the numerical primary guides for limiting worker exposure to radiation. EPA, working in coordination with agencies of the governmental Interagency Steering Committee on Radiation Standards (ISCORS), has been revising its "Federal Radiation Protection Guidance for Exposure of the General Public" for issuance in the near future; that document last published in 1960, was revised in draft in 1994, and has been undergoing significant revisions since that time.

EPA regulates radon and radioisotope emissions through its authority under the Clean Air Act (42 USC 7401 et seq.) (1970). Regulations promulgated by the Agency that control radioactive facilities and sites include 40 CFR Part 61:

- Subpart B, Underground Uranium Mines
- Subpart H, Department of Energy Facilities
- Subpart I, Certain non-DOE Facilities

- Subpart K, Elemental Phosphorous Plants
- Subpart Q, DOE Facilities Radon Emissions
- Subpart R, Radon from Phosphogypsum Stacks

Under the Radon Gas and Indoor Air Quality Research Act (USC 42 et seq.) (1986) and Indoor Radon Abatement Act (1988), as well as authorities of the Clean Air Act, EPA has developed guidance for control of radon in buildings and schools. The guidance for radon has been generally adopted as a standard for use in establishing cleanups of radioactively contaminated sites. Although indoor radon exposures are believed by the radiation protection community to be the largest radiation related risk, indoor radiation does not arise from the low-activity wastes dealt with in this report.

The Clean Water Act's (CWA) (33 USC 121 et seq.) (1977) primary objective is to restore and maintain the integrity of the nation's waters. This objective translates into two fundamental national goals: eliminate the discharge of pollutants into the nation's waters, and achieve water quality levels that are fishable and swimmable. Under this law, EPA is given the authority to establish water quality standards and regulate the discharge of pollutants into waters of the United States. Section 502(6) of the CWA includes radioactive materials in the definition of pollutants. EPA's implementing regulations at 40 CFR 122.2, which define the term pollutant, include radioactive materials except those regulated under the Atomic Energy Act. Thus EPA currently regulates radionuclides and radiation in discharges and establishes water quality standards. This includes TENORM radionuclides with the exception of uranium and thorium.

The Safe Drinking Water Act (SDWA)(42 USC 300f et seq.) (1974), is the main federal law that ensures the quality of Americans' drinking water. Under SDWA, EPA sets standards for drinking water quality and oversees the states, localities, and water suppliers who implement those standards. Implementing regulations for 40 CFR 141 include the establishment of national primary drinking water standards which currently include maximum contaminant limit goals (MCLG) and maximum contaminant limits (MCL) for radiation and radionuclides; current standards include radium-226 and radium-228, uranium, combined alpha, and beta and photon emitters. MCLs have also been proposed for Radon.

The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) (42 USC 9601 et seq.) (1980) and the Superfund Amendments and Reathorization Act (SARA) (42 USC 9601 et seq) (1986) created a tax on the chemical and petroleum industries and provided broad Federal authority to respond directly to releases or threatened releases of hazardous substances that may endanger public health or the environment. CERCLA established prohibitions and requirements concerning closed and abandoned hazardous waste sites; provided for liability of persons responsible for releases of hazardous waste at these sites; and established a trust fund to provide for cleanup when no responsible party could be identified. EPA has determined that radiation is a carcinogen and thus a hazardous substance. Under the National Oil and Hazardous Substances Contingency Plan, EPA has issued guidance on removals and clean up of radioactively contaminated sites. Implementing regulations for the NCP are found at 40 CFR 300.

The Toxic Substances Control Act (TSCA) (15 USC 2601 et seq.) (1976) was enacted by Congress to give EPA the ability to track the 75,000 industrial chemicals currently produced or imported into the United States. EPA repeatedly screens these chemicals and can require reporting or testing of those that may pose an environmental or human-health hazard. EPA can ban the manufacture and import of those chemicals that pose an unreasonable risk. While radionuclides are considered toxic substances under the act, source material, special nuclear material, or byproduct material (as such terms are defined in the Atomic Energy Act of 1954 (42 USC. 2011 et seq.) and regulations issued under such Act) are excluded from coverage. Consequently, TENORM radionuclides may be subject to this law.

The Resource Conservation and Recovery Act (RCRA) (42 USC 321 et seq.) (1976) gave EPA the authority to control hazardous waste. This includes the generation, transportation, treatment, storage, and disposal of hazardous waste. RCRA also set forth a framework for the management of non-hazardous solid waste. The 1986 amendments to RCRA enabled EPA to address environmental problems that could result from underground tanks storing petroleum and other hazardous substances. RCRA focuses only on active and future facilities and does not address abandoned or historical sites (see CERCLA). The Hazardous and Solid Waste Amendments (HSWA) are the 1984 amendments to RCRA that restricted land disposal of hazardous waste. Some of the other mandates of this strict law include increased enforcement authority for EPA, more stringent hazardous waste management standards, and a comprehensive underground storage tank program. RCRA specifically excludes source, special nuclear, and byproduct material from its jurisdiction. EPA's implementing regulations for RCRA do not address, but also do not prohibit, disposal of radioactively contaminated substances in landfills. With the approval of the appropriate regulatory authority, such facilities have been used for disposal of TENORM, nuclear accelerator wastes, and certain AEA materials.

Additional radiation protection authorities provided to the EPA by Congress include responsibilities for setting protective standards for radioactive waste disposal. Under the Waste Isolation Pilot Plant Land (WIPP) Withdrawal Act, as amended (P.L. 102-579, 106 Stat. 4777), Congress gave EPA the authority to regulate many of the Department of Energy's activities concerning this radioactive waste disposal site in New Mexico. EPA was required to finalize regulations which apply to all sites—except Yucca Mountain—for the disposal of spent nuclear fuel, transuranic and high-level radioactive waste. In 1998, EPA granted a certification of compliance indicating that the WIPP complied with EPA's radioactive waste disposal regulations and could open to receive these materials. The compliance criteria regulations were established by EPA in 40 CFR 194 and the disposal regulations set by EPA in 40 CFR 191.

The Energy Policy Act of 1992 (42 USC 10141 n), Section 801, required the EPA, based upon and consistent with the findings and recommendations of the National Academy of Sciences, to develop regulations on health and safety standards for protection of the public from releases from radioactive materials stored or disposed of in the proposed Yucca Mountain radioactive waste disposal site. The standards to be developed were required to prescribe the maximum annual effective dose equivalent to individual members of the public from releases to the accessible environment from radioactive materials stored or disposed of in the repository. In 1999, EPA proposed draft standards and held public hearings; final regulations were published in 2001 for use by the Nuclear Regulatory Commission and Department of Energy.

Current regulations applicable to remediation of both inactive uranium mill tailings sites, including vicinity properties, and active uranium and thorium mills have been issued by the EPA under the Uranium Mill Tailings Radiation Control Act (UMTRCA) (42 USC 2022 et seq.) of 1978, as amended. EPA's regulations in 40 CFR 192 apply to remediation of such properties and address emissions of radon, as well as radionuclides, metals, and other contaminants into surface and groundwater.

Appendix D
Disposal Sites and Operations[1]

BARNWELL, SOUTH CAROLINA

Chem-Nuclear's Barnwell, South Carolina, low-level radioactive waste facility has been in commercial operation since 1971. The 235-acre facility occupies property owned by the State of South Carolina and leased to Chem-Nuclear Systems. The Barnwell Waste Management Facility operates under the authority of Radioactive Material License 097 issued by the South Carolina Department of Health and Environmental Control (DHEC). About 28 million cubic feet or 90% of the available disposal volume has been used.

Much of low-level radioactive waste looks like ordinary trash. It consists of contaminated wood, concrete, glass, metal, fabric, paper and resins. All waste accepted for disposal must be in a dry, solid form. No liquid waste is accepted for disposal. No toxic chemical waste or high-level radioactive wastes, such as spent fuel from nuclear reactors, are acceptable at the disposal site.

Prior to disposal, the radioactive waste is packaged inside containers for safe handling and transport. Once at the Barnwell site, these waste containers are placed in large concrete vaults located in engineered earthen trenches (disposal cells) excavated up to 25 feet below grade.

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[1] Information in this Appendix was based in internet material posted by each operator, as noted herein. It has not been evaluated by the committee.

The principal disposal area is the trench itself. Just as the waste must be in a dry, solid form, the design of the trench, the vaults and the method of filling them keeps the waste dry. By minimizing the contact between the waste and rainwater, the disposal system reduces the possibility of radioactive materials entering the natural environment.

The clay and sand soil of the Barnwell facility has been in place for millions of years. Each trench excavated in this material includes a drainage collection system sloping toward a French drain that leads to a sump. Standpipes allow monitoring of rainwater should it enter the trench. A sand layer covers the bottom of the trench. Technicians at the disposal site place the waste containers in large concrete containers, or vaults. When a vault is full, its concrete lid is put in place. One to two additional vaults may be placed on top until the vaults are stacked up to three high. Vaults provide long-term structural stability for the completed trench. Backfill soil is placed around and over the filled concrete vaults. Finally, an engineered cap consisting of multiple layers of sand, clay, high density polyethylene and top soil covers the trench area. Shallow rooted grasses planted on top of the cap control erosion. This cap serves as a barrier to help isolate the trench from rainwater infiltration.

Since 1990, Chem-Nuclear has installed engineered caps on older, filled trenches at the disposal site. A buffer zone between the trenches and the nearest property adds an additional margin of safety.

The Barnwell site is one of the world's most heavily studied and monitored parcels of land. A comprehensive environmental monitoring program includes air, surface water, groundwater, vegetation and soil samples. In addition to an extensive network of monitoring wells both on and off-site, an on-site weather station records wind speed, temperature and humidity.

Low-level radioactive waste decays relatively quickly to insignificant levels. The rate of decay and the concentration of radionuclides varies widely from one kind of low-level waste to another. Of the waste disposed at the Barnwell facility, about 90 percent of the radioactivity will have decayed within 100 years after the site closes. A long term care fund is set up and held in escrow by the state to pay for monitoring and maintenance during the institutional control period.

SOURCE: <http:// www.chemnuclear.com>

CLIVE, UTAH

Envirocare of Utah disposes of waste material in above-ground, engineered disposal cells located near Clive, Utah. The cells are patterned after DOE and EPA specifications that meet 40 CFR 264 and NRC disposal requirements. Mixed waste materials are placed using the same procedures as for low level radioactive and NORM materials.

Disposal Practices

Debris Waste

- Regular Debris. Envirocare's procedures for placement of all non-soil like or solid debris material is designed to minimize the possibility of voids that would compromise cell integrity through settlement. Regular sized debris is placed in 12-inch lifts, each of which is compacted to 90 percent of its optimum density in a continuous cut and cover process.
- Oversized Debris. Materials that exceed the dimensions specified as "regular" in Envirocare's Radioactive Materials License (at this date, 12' x 12' x 10") and/or materials with density greater than 70 pounds per cubic foot, are handled one of two ways: 1) Materials are placed in the lift and soil is compacted in and around the debris to eliminate voids; 2) Materials are placed in forms in the cell, after which a controlled low strength material (CLSM) or "flowable fill" is poured to create a monolithic form to fill the void spaces.

Naturally Occurring Radioactive Material (NORM)

Disposal operations for material have been performed in accordance with Envirocare's Radioactive Material License (UT 2300249). Envirocare accepts and disposes of NORM material for direct disposal. NORM material is mainly shipped bulk via rail. Envirocare currently has the capacity to dispose of 2 Million cubic yards of NORM waste.

Low-Level Radioactive Waste

Envirocare is licensed to accept Class A Low-Level Radioactive Waste for disposal. The State of Utah, an NRC-Agreement State, maintains the licensing responsibility for low-level waste management under the Envirocare Radioactive Materials License.

11e.(2) Byproduct Material

The disposal of 11e.(2) waste is in accordance with Envirocare's 11e.(2) materials license (SMC-1559) issued by the U.S. Nuclear Regulatory Commission. Envirocare accepts and disposes of 11e.(2) byproduct material for direct disposal.

Mixed Waste

Envirocare's Clive, Utah site is a Resource Conservation Recovery Act (RCRA) facility that is licensed by the State of Utah and the EPA to receive, possess, use, treat, and dispose of mixed radioactive materials. Envirocare's RCRA Part B permit authorizes the disposal of both characteristic and listed wastes meeting land disposal restrictions.

Treatment Practices

Envirocare has constructed additional structures to expand its mixed waste operations. A second building now houses a large treatment and storage area, drum stabilization process, and large mixed waste stabilization technology, in addition to PCB and Organics removal technologies. The building is designed as a multi-purpose RCRA containment facility. The mixed waste treatment facility incorporates treatment technologies designed to reduce toxicity of waste materials prior to disposal. Current mixed waste technologies are shown below; future capabilities, currently in development, include treatment for mercury and organics.

Stabilization	Reduction/Oxidation
Deactivation	Chemical Fixation
Neutralization	Polymer Encapsulation

Envirocare's stabilization facility is permitted to treat 150 tons of material per day, while the permits do not restrict the macroencapsulation facility to particular capacity. Each treatment process involves development of a treatment formula, which is created by conducting bench-scale testing of the waste material using commercially available treatment chemicals. Disposal of the treated residue occurs after verification that the material meets applicable treatment standards.

SOURCE: <http://envirocareutah.com>

RICHLAND, WASHINGTON

U.S. Ecology disposes of USNRC Class A, B and C low-level radioactive waste at its site near Richland, Washington. This site has successfully operated on the Department of Energy's Hanford Reservation since 1965. The facility also offers permanent isolation of exempt source and byproduct material, as well as naturally occurring and accelerator-produced radioactive materials (NARM) from customers worldwide, including universities, nuclear power plants, mining companies, medical centers, manufacturing, petrochemical and biotechnology companies, military installations and numerous other government agencies. The Richland site offers more than 45 million cubic feet of unused

disposal capacity sufficient to accept large quantities of waste well into the 21st century.

GRAND VIEW, IDAHO

U.S. Ecology Idaho operates a fully permitted treatment and disposal facility for chemically hazardous wastes near Grand View, Idaho. The Army Corps of Engineers is currently disposing of FUSRAP wastes at this site.

The site offers industry-standard and patented processes to safely treat and dispose of a broad range of RCRA hazardous waste, certain naturally occurring radioactive materials, and PCB wastes. Services include:

- Hazardous, PCB and NORM waste disposal
- Stabilization of metal bearing wastes
- Encapsulation of debris
- Full PCB transformer processing
- Liquid waste evaporation
- Patented K061 steel mill waste "delisting" treatment

The site is located in the Owyhee Desert of southwestern Idaho, a region with an arid climate, deep groundwater, and favorable geology—the right conditions for permanent waste isolation. Located on a major rail line, US Ecology Idaho's rail transfer facility offers cost-effective access. Wastes arrive by railcar from throughout theUnited States. At the on-site railhead, gondola and hopper car shipments can be received and unloaded around the clock. Intermodal containers can be received by truck or rail.

U.S. Ecology Idaho also accepts waste in drums, super sacks, roll-off containers, intermodal containers and dump trucks.

SOURCE: <http://www.americanecology.com>

Appendix E
The McMahon Act

The McMahon Act (Atomic Energy Act of 1946) was focused on safeguards and security for materials that have significance in the development of "atomic fission." The Atomic Energy Act was significantly rewritten as the more familiar Atomic Energy Act of 1954. This version with several major amendments of its coverage and content comprises today's regulations from the Nuclear Regulatory Commission. Nonetheless the very first definitions that were designed to provide safeguards and security of materials involved in "atomic fission" survive with only slight changes in wording today.

The 1946 definitions were:

(b) Source Materials.

(1) Definition. The term "source materials" shall include any ore containing uranium, thorium, or beryllium, and such other materials peculiarly essential to the production of fissionable materials as may be determined by the Commission with the approval of the President.

(2) License for Transfers Required. No person may transfer possession or title to any source material after mining, extraction, or removal from its place of origin, and no person may receive any source material without a license from the Commission.

(3) Issuance of Licenses. Any person desiring to transfer or receive possession of any source material shall apply for a license therefore in accordance with such procedures as the Commission may by regulation establish. The Commission shall establish such standards for the issuance or refusal of licenses, as it may deem necessary to assure adequate source materials for production, research or developmental activities pursuant to this Act or to prevent the use of such materials in a manner inconsistent with the national welfare.

(c) Byproduct Materials.

(1) Definition. The term "byproduct material" shall be deemed to refer to all materials (except fissionable material) yielded in the processes of producing fissionable material.

(2) Distribution. The Commission is authorized and directed to distribute, with or without charge, byproduct materials to all applicants seeking such materials for research or developmental work, medical therapy, industrial uses, or such other useful applications as may be developed, if sufficient materials to meet all such requests are not available, the Commission shall allocate such materials among applicants therefore, giving preference to the use of such materials in the conduct of research and developmental activity and medical therapy. The Commission shall refuse to distribute or allocate any byproduct materials to any applicant, or recall any materials after distribution or allocation from any applicant, who is not equipped or who fails to observe such safety standards to protect health as may be established by the Commission.

Sec. 5. (a)(1) Definition. The term "fissionable materials" shall include plutonium, uranium 235, and such other materials as the Commission may from time to time determine to be capable of releasing substantial quantities of energy through nuclear fission of the materials.

(2) Privately Owned Fissionable Materials. Any person owning any right, title, or interest in or to any fissionable material shall forthwith transfer all such right, title, or interest to the Commission.

(3) Prohibition. It shall be unlawful for any person to (a) own any fissionable material; or (b) after sixty days after the effective date of this Act and except as authorized by the Commission possess any fissionable material; or (c) export from or import into the United States any fissionable material, or directly or indirectly be a party to or in any way a beneficiary of, any contract, arrangement or other activity pertaining to the production, refining, or processing of any fissionable material outside of the United States.

(4) Distribution of Fissionable Materials. The Commission is authorized and directed to distribute fissionable materials to all applicants requesting such materials for the conduct of research or developmental activities either independently or under contract or other arrangement with the Commission. If sufficient materials are not available to meet all such requests, and applications for licenses under section 7, the Commission shall allocate fissionable materials among all such applicants in the manner best calculated to encourage independent research and development by making adequate fissionable materials available for such purposes. The Commission shall refuse to distribute or allocate any materials to any applicant, or shall recall any materials after distribution or allocation from any applicant, who is not equipped or who

fails to observe such safety standards to protect health and to minimize danger from explosion as may be established by the Commission."

Appendix F
Committee Biographies

Chairman

David H. Leroy has his own law practice in Boise, Idaho, which specializes in governmental and administrative law issues. He has extensive experience in the legal, policy, and political arenas. As an appointee of President George H. Bush, he was confirmed by the Senate in August 1990 as the first U.S. waste negotiator, a post created by Congress in the 1987 Waste Policy Amendments Act to assist the government in siting a geologic repository for high-level waste. In 1993 Mr. Leroy turned his attention to low-level waste, especially the general failure of the 1980 Low-Level Waste Policy Act. Recently he has sought to develop improved technical and public policy solutions for managing low-level waste, including the assured storage concept. Before his appointment as waste negotiator, he served as Lieutenant Governor of Idaho and Idaho Attorney General. He has made numerous presentations and authored a variety of publications, including reports on low-level waste disposal, repository siting, and negotiation. Mr. Leroy received his B.S. in 1969 and J.D. in 1971 from the University of Idaho, and Master of Laws in Trial Practice and Procedure in 1972 from New York University School of Law.

Vice Chairman

Michael T. Ryan is an independent consultant in radiological sciences and health physics. He is an adjunct associate professor in the College of Health Professions at the Medical University of South Carolina. He is also an adjunct faculty member at the Charleston Southern University and the College of Charleston. Dr. Ryan is editor-in-chief of *Health Physics Journal*. Recently he was appointed by the Nuclear Regulatory Commission to a four-year term (2002-2006) as a member of the Advisory Committee on Nuclear Waste (ACNW). In addition, he is currently serving on the Scientific Review Group appointed by the Assistant Secretary of Energy to review the ongoing research in health effects at the former Soviet weapons complex sites the Southern Urals and on two committees of the National Academies. In 1996-1997 Dr. Ryan was the vice president of Barnwell Operations for Chem-Nuclear Systems, Inc., where he had overall responsibility for operation of the low-level radioactive waste disposal and service facilities in Barnwell, South Carolina. From 1984 to 1996 he served as the company's director, and then vice president of regulatory affairs with the responsibility for developing and implementing regulatory compliance policies and programs to comply with state and federal regulations. Before that, Dr. Ryan spent seven years in environmental health physics at Oak Ridge National Laboratory. Dr. Ryan received his Ph.D. in 1982 from the Georgia Institute of Technology, where he was recently inducted into the Academy of Distinguished Alumni. He earned his M.S. in radiological sciences and protection from the University of Lowell, Mass. in 1976 and his B.S. in radiological health physics from Lowell Technological Institute in 1974. He is a recipient of the University of Massachusetts-Lowell's Francis Cabot Lowell Distinguished Alumni for Arts and Sciences Award.

Committee Members:

Edward Albenesius retired in 1992 as manager of the advanced waste technology division and senior advisory scientist at the Savannah River Site, SC. His expertise includes treating and disposing of low-level and transuranic waste from nuclear fuel reprocessing and nuclear materials production for national defense, environmental monitoring, and health physics. He conceived and implemented the first integrated program for managing low-level wastes at a major DOE site, resulting in large reductions in waste volume and disposal in engineered facilities—departing from earlier practices of disposal in open trenches. Dr. Albenesius also held temporary assignments with the Department of Energy (DOE) where he coordinated the revision of DOE Order 5820.2A on radioactive waste management and with several task forces for the Nuclear Regulatory Commission and the National Council on Radiation Protection (NCRP). As a consultant to the International Atomic Energy Agency in 1995 he helped prepare management plans for low-activity waste and spent sealed sources for 20 developing countries. Dr. Albenesius received his Ph.D. degree in organic chemistry from the University of North Carolina in 1952 and his A.B. degree in chemistry from the College of Charleston, SC in 1947.

Wm. Howard Arnold (NAE) retired in1989 as general manager of the advanced energy systems division of Westinghouse Electric Company. His primary area of expertise is in the commercial nuclear fuel cycle, including nuclear power, fuel, and waste management. He has managed multi-disciplinary groups of engineers and scientists working in reactor core design and led work that promoted the use of centrifuge technology in uranium enrichment. Dr. Arnold's experience includes managing residues from uranium enrichment and low-activity wastes from reactor operation and spent fuel storage. As vice president, Westinghouse Hanford Company, he was responsible for engineering, development, and project management at the Hanford Site from 1986-1989. He was elected to the National Academy of Engineering in 1974. Recently Dr. Arnold has been involved in an advisory capacity in the cleanup of DOE nuclear weapons material productions sites, especially in the vitrification plant at the Savannah River Site. Currently he is chairman of the National Academies' Committee on Improving the Scientific Basis for Managing Nuclear Materials and Spent Nuclear Fuel. He received his A.B. in 1951 from Cornell University, and his M.A. 1953 and Ph.D. in physics in 1955, both from Princeton University.

François Besnus is head of the office for safety evaluation of radioactive waste disposal in the Institute of Radiological Protection and Nuclear Safety (IRSN), Fountenay aux

Roses, France. His current work includes evaluating the safety of near surface disposals of low- and intermediate-activity waste in France and participating in the development of safety standards for the European Union. Previously as a staff officer in the IRSN department for protection of man and the environment, he was in charge of very low-level and mining and milling waste management. He helped to establish French collaborations with eastern countries for assessing the extent of radioactivity migration in the Chernobyl area and for managing the large volumes of low-activity waste that resulted from the cleanup of contaminated areas. Dr. Besnus received his Ph.D. in radiochemistry in 1991, an M.S. degree in radiochemistry in 1986, and an M.S. degree in geology in 1985, all from Paris XI University.

Perry H. Charley is director of the uranium education and geographical information systems programs within the division of math, science, and technology at the Shiprock campus of Dinè College, NM, a Navajo institution. Mr. Charley has over 30 years of experience performing environmental, health impact, and psycho-social impact studies. Currently he is the principal investigator of four epidemiological research projects, the foremost being a DNA damage study of Navajo communities impacted by past uranium mining practices. From 1983 through 1999 he held several positions for the DOE and EPA uranium mill tailings remedial action (UMTRA) project, including director of the Navajo Nation's UMTRA program and the Navajo Abandoned Mine Reclamation Program. He has served on several EPA advisory committees. Mr. Charley received his B.S. degree in environmental science from the University of Arizona in 1979.

Gail Charnley is principal of HealthRisk Strategies, a consulting firm in Washington, DC. Dr. Charnley's areas of expertise are toxicology, environmental health risk assessment, and risk management science and policy. She writes and speaks extensively on issues related to the role of science and risk analysis in environmental health policy and decision-making. She is an adjunct faculty member in the Harvard School of Public Health's Center for Risk Analysis and has chaired or served on numerous peer review panels convened by the Environmental Protection Agency and the Food and Drug Administration. During its tenure, she was executive director of the Presidential/Congressional Commission on Risk Assessment and Risk Management, mandated by Congress to evaluate the role that risk assessment and risk management play in federal regulatory programs. Before her appointment to the Commission, she served as acting director of the toxicology and risk assessment program at the National Academies. She has been the project director for several National Academies committees, including the Committee on Risk Assessment Methodology and the Complex Mixtures Committee, and served as the chair of several U.S. Army Science Advisory Board committees that evaluated health risk assessment practices in the Army. Dr. Charnley received her Ph.D. in toxicology from the Massachusetts Institute of Technology in 1984 and her A.B. (with honors) in molecular biology from Wellesley College in 1977.

Sanford Cohen is the founder and president of SC&A, Inc., an energy and environmental consulting firm providing expertise in radiation sciences, management, health and safety analyses, communications services, and information management. He has managed several contracts for agencies of the U.S. Government, including the Environmental Protection Agency, the Centers for Disease Control, the Council on

Environmental Quality, the Congressional Office of Technology Assessment, the Department of Energy, and the Nuclear Regulatory Commission. Dr. Cohen is involved in regulatory guidance pertaining to environmental management (including RCRA/CERCLA requirements), the remediation of contaminated sites, safe disposal of hazardous wastes, site characterization in support of decontamination and decommissioning projects, recycling of scrap metal from nuclear facilities, electric and magnetic fields effects, and indoor air quality. He was a member of the National Academies' Committee on Characterization of Remote-Handled Transuranic Waste for the Waste Isolation Pilot Plant. Prior to founding SC&A in 1981, Dr. Cohen was the vice president and manager of Teknekron, Inc.'s Washington operations and president of Teknekron Research, Inc., a consulting group working with the governmental agencies listed above. Dr. Cohen earned his B.S. in science engineering at Northwestern University and his Ph.D. in nuclear engineering at the University of Michigan.

F. Stanley Echols is a principal of the Echols Consulting Group in Washington, DC. Dr. Echols has over 20 years experience in both the public and private sectors drafting, commenting upon, challenging, and implementing USNRC, EPA, and DOE radiological regulations and guidance documents that address the protection of public health and safety and the environment. He specializes in providing assistance in a broad range of technical, regulatory and legal matters, including the evaluation of risk-informed, performance-based safety assessments—as opposed to exclusively deterministic assessments. Before starting his own firm Dr. Echols was a partner in a national law firm where he managed a team of attorneys assisting clients in regulatory matters, an attorney at the Department of Energy, a Special Assistant U.S. Attorney for the District of Columbia, a project manager for the USNRC, and a project engineer for an architect-engineering firm. Dr. Echols received his Ph.D. in environmental engineering from the University of Florida after working as a doctoral research fellow at Oak Ridge National Laboratory. He holds an M.B.A. in management and B.S. in nuclear engineering sciences from the University of Florida. Dr. Echols also received a J.D. degree in law from the Georgetown University.

Sharon Friedman is professor of journalism and communication and director of the science and environmental writing program at Lehigh University in Bethlehem, PA. Her research and consulting activities focus on how scientific, environmental, and health risk issues are communicated to the public. Prof. Friedman chaired the Department of Energy's Advisory Committee for its low dose radiation research program. She has served as a consultant to the President's Commission on the Accident at Three Mile Island, the United Nations Economic and Social Commission for Asia and the Pacific, and various U.S. government agencies and industries on environmental and risk communication. Elected a Fellow of the American Association for the Advancement of Science (AAAS) in 1989 for her contributions toward furthering the public understanding of science and technology, she is a member of the AAAS Council. She served as a Fulbright Distinguished Lecturer in Brazil and a Bosch Foundation Lecturer in Germany. Prof. Friedman is associate editor of the journal, *Risk: Health, Safety and Environment*, and a member of the editorial advisory board of the journal, *Science Communication*. She is a member of the National Academies' Committee on Assessment of the Centers for Disease Control and Prevention's Radiation Studies. She received her M.A. in Journalism from Pennsylvania State University in 1974, a graduate certificate in public relations from American University in 1970, and her B.A. in biology from Temple University in 1964.

Maurice Fuerstenau (NAE) is professor of metallurgy at the Mackay School of Mines, University of Nevada, Reno. His expertise is in mineral extraction, processing, and hydrometallurgy. His work covers ore benefaction and dealing with residues, which include technologically enhanced naturally occurring radioactive materials (TENORM). Among his numerous refereed publications and books, Dr. Fuerstenau has recently completed the two volume *Principles of Mineral Processing*. He has been recognized by awards from the American Institute of Mining and Metallurgical Engineers, and by election to the National Academy of Engineering (NAE) in 1991. He has served as member, vice chair, and chair of committees of the NAE section on petroleum, mining, and geological engineering. He currently serves on the NAE committee on membership. Dr. Fuerstenau received his Sc.D. in 1961 and S.M. in 1957 from the Massachusetts Institute of Technology, and his B.S. in 1955 from the South Dakota School of Mines.

James T. Hamilton is associate professor of public policy, economics, and political science at Duke University, where he served as associate director of the Sanford Institute for Public Policy. His expertise includes the economics of regulation, public choice in a political economy, and environmental policy. Dr. Hamilton's numerous publications include the book, *Calculating Risks: The Spatial and Political Dimensions of Hazardous Waste Policy,* coauthored with W. Kip Viscusi (MIT Press 1999). His article "Testing for Environmental Racism: Prejudice, Profits, Political Power?" Journal of Policy Analysis and Management 14:1 (Winter 1995) won the journal's best article of the year award. In 2001 he won the Association for Public Policy Analysis and Management's David N. Kershaw award. He earned his Ph.D. in economics in 1991 and his B.A. summa cum laude in economics and government in 1983, both from Harvard.

Ann Rappaport is a faculty member in the department of urban and environmental policy and planning at Tufts University. She held previous appointments in the department of civil and environmental engineering and in the center for environmental management at Tufts. Her work deals with both the technical and policy challenges of managing hazardous waste: health effects, site assessment and management, waste reduction and treatment, and risk assessment and management—with an emphasis on corporate responsibility and decision making. Her research has examined environmental, health, and safety programs in multinational corporations. Dr. Rappaport has published two books, several chapters, and numerous articles and reports. She was a member of the international committee of the National Advisory Council for Environmental Policy and Technology for the Environmental Protection Agency. She also served on the National Academies' Committee on Evaluation Protocols for Commercializing Innovative Remediation Technologies. Dr. Rappaport received her Ph.D. in civil engineering from Tufts University in 1992, her M.S. in civil engineering from the Massachusetts Institute of Technology in 1976, and her B.A. in Asian and environmental studies from Wellesley College in 1973.

D. Kip Solomon is an associate professor in the Department of Geology and Geophysics at the University of Utah. He specializes in fluid flow in soils and shallow aquifers, emphasizing the fate and transport of contaminants. Dr. Solomon has also worked on techniques for determining the age of shallow groundwater using tritium and helium isotopes and using these tools to examine fluid flow in porous and fractured systems. He won the outstanding faculty research award in his department in 1997-98 and was associate editor of *Ground Water* from 1996-2001. He served on the National Academies' Panel on Conceptual Models of Flow and Transport in the Fractured Vadose Zone from 1998 to 2001. Dr. Solomon received his B.Sc. in geological engineering in 1983 and his M.Sc. in geology in 1985 from the University of Utah, and his Ph.D. in earth sciences in 1992 from the University of Waterloo.

Kimberly Thomas is deputy division leader of the chemistry division at Los Alamos National Laboratory (LANL). Her expertise includes managing wastes from research and medical isotope production. Dr. Thomas has supervised all aspects of medical isotope production at LANL. She has also directed research on accelerator transmutation of waste, geochemical behavior of radionuclides, actinide bioassay measurements, nuclear weapons debris analyses, processing of uranium ores, and fundamental actinide chemistry. She has evaluated how options for treating Hanford tank waste and for accelerator transmutation of wastes would fit with waste acceptance criteria for geological disposal. Dr. Thomas is a member of the American Chemical Society's division of nuclear chemistry and technology and the Network for Women in Science, and she has served on the DOE advisory committee on nuclear and radiochemistry education. In 2000, she received a LANL outstanding mentoring award for her work in fostering career development of women and members of her community. Dr. Thomas received her Ph.D. in nuclear chemistry as a student of Glenn Seaborg and her Master of Bioradiology, both from the University of California-Berkeley. She received her A.B. in chemistry from Middlebury College.

Appendix G
Acronym List

AEA	Atomic Energy Act (1954)
AEC	Atomic Energy Commission
ALARA	As Low As Is Reasonably Achievable
ARARS	Applicable or Relevant and Appropriate Requirements
BEIR	Biological Effects of Ionizing Radiation (NRC Committee)
BRWM	Board on Radioactive Waste Management
CAA	Clean Air Act
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act (1980, known as "Superfund")
CFR	Code of Federal Regulations
CID	Central Internet Database
CLSM	Controlled Low-Strength Material (used as a filler for waste disposal)
CRCPD	Conference of Radiation Control Program Directors
CWA	Clean Water Act
DHEC	South Carolina Department of Health and Environmental Control
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy

DOT	U.S. Department of Transportation
EIS	Environmental Impact Statement
EM	Office of Environmental Management (DOE)
EPA	U.S. Environmental Protection Agency
ERDA	Energy Research and Development Administration
ERDF	Environmental Restoration Disposal Facility (at Hanford, Washington)
FRC	Federal Radiation Council
FUSRAP	Formerly Utilized Sites Remedial Action Program
GAO	U.S. General Accounting Office
GTCC	Greater-Than-Class-C
HLW	High-Level Waste
HSWA	Hazardous and Solid Waste Amendments
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ISCORS	Interagency Steering Committee on Radiation Standards
LAW	Low-Activity Waste
LLW	Low-Level Waste
LLWPA	Low-Level Waste Policy Act (1980, amended 1985)
MCL	Maximum Contaminant Level
MCLG	Maxiumum Containment Limit Goals
MIMS	Manifest Information Management System
MLLW	Mixed Low-Level Waste
NARM	Naturally Occurring and Accelerator-Produced Radioactive Material
NCRP	National Council on Radiation Protection and Measurement

NEPA	National Environmental Policy Act (1969, amended 1970)
NESHAPs	National Emissions Standards for Hazardous Air Pollutants
NARM	Naturally Occurring and Accelerator-Produced Radioactive Materials
NORM	Naturally Occurring Radioactive Materials
NPDES	National Pollutant Discharge Effluent Standards
NRC	National Research Council
NWPA	Nuclear Waste Policy Act (1982)
OSWER	Office of Solid Waste and Emergency Response
RPP	Radiation Protection Program
RCRA	Resource Conservation and Recovery Act (1976, amended 1984)
Rem	Roentgen Equivalent Man
ROD	Record of Decision
SARA	Superfund Amendments and Reauthorization Act of 1986
SECC	Southeast Compact Commission
SDWA	Safe Drinking Water Act
SNF	Spent Nuclear Fuel
Superfund	Hazardous Substance Response Trust Fund (CERCLA)
TENORM	Technologically Enhanced NORM
TRU	Transuranic
TSCA	Toxic Substances Control Act
UMTRCA	Uranium Mill Tailings Radiation Control Act
USACE	U.S. Army Corps of Engineers
USNRC	U.S. Nuclear Regulatory Commission
WIPP	Waste Isolation Pilot Plant