RECEIVED

NOV 01 1994

OSTI

Directions in Low-Level Radioactive Waste Management:

A Brief History of Commercial Low-Level Radioactive Waste Disposal

Published August 1994

Idaho National Engineering Laboratory
EG&G Idaho, Inc.
Idaho Falls, Idaho 83415

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Prepared for the
U.S. Department of Energy
Assistant Secretary for Environmental Management
Under DOE Idaho Operations Office
Contract DE-AC07-76ID01570

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

87D

DISCLAIMER

**Portions of this document may be illegible
in electronic image products. Images are
produced from the best available original
document.**

ABSTRACT

This report presents a history of commercial low-level radioactive waste disposal in the United States, with emphasis on the history of six commercially operated low-level radioactive waste disposal facilities. The report includes a brief description of important steps that have been taken during the last decade to ensure the safe disposal of low-level radioactive waste in the 1990s and beyond. These steps include the issuance of comprehensive State and Federal regulations governing the disposal of low-level radioactive waste, and the enactment of Federal laws making States responsible for the disposal of such waste generated within their borders.

FOREWORD

As part of the effort by the U.S. Department of Energy's National Low-Level Waste Management Program to develop and make available useful information concerning low-level radioactive waste management, this report describes the development of low-level radioactive waste disposal in the U.S. It includes early practices and experiences, the development of comprehensive Federal and State regulations, and the enactment of Federal legislation that assigns responsibilities and creates the framework under which low-level radioactive waste management and disposal operations are now carried out. It also contains a summary of the operational histories of commercially operated low-level radioactive waste disposal facilities in the United States.

This examination of the history of low-level radioactive waste disposal practices and of the development of the regulations governing these practices is intended to be instructive and to provide a basic understanding of commercial low-level radioactive waste disposal in the United States today. To that end, the report has been written for readers who do not have extensive backgrounds in low-level radioactive waste management, but who are interested in its history and in current practices.

The report is divided into two parts. Part One presents a history of low-level radioactive waste management, dividing the information into historical periods. Part Two provides specific operating histories of the six disposal sites. A glossary of terms is included. The appendices provide further information on radioactive decay, radionuclide migration, performance assessment, and disposal technologies. In addition, a reading list has been furnished. The material used in preparing this document was obtained from existing records and reports, State and Federal officials, and site operators. A bibliography is provided at the end of the document.

This is an update of a previously issued Department of Energy report, *Directions in Low-Level Radioactive Waste Management: A Brief History of Commercial Low-Level Radioactive Waste* (DOE/LLW-103), dated October 1990.

CONTENTS

ABSTRACT	iii
FOREWORD	v
INTRODUCTION	1
PART ONE: LOW-LEVEL RADIOACTIVE WASTE DISPOSAL	3
Early Practices, 1960-1980	4
Regulatory Reform, 1980-1985	6
State Involvement, 1980-1994	8
PART TWO: HISTORIES OF SIX LOW-LEVEL RADIOACTIVE WASTE DISPOSAL FACILITIES	12
Beatty, Nevada	12
Site Description	12
Operating History	12
Facility Status	16
Maxey Flats, Kentucky	16
Site Description	16
Operating History	18
Basis for Facility Closure	20
Postclosure History	20
Facility Status	21
West Valley, New York	22
Site Description	23
Operating History	26
Basis for Facility Closure	26
Postclosure History	26
Facility Status	28
Richland, Washington	29
Site Description	29
Operating History	29
Facility Status	33

The Future	33
Sheffield, Illinois	34
Site Description	34
Operating History	34
Basis for Facility Closure	37
Postclosure History	38
Facility Status	38
Barnwell, South Carolina	39
Site Description	39
Operating History	41
Facility Status	43
The Future	44
GLOSSARY	46
READING LIST	49
BIBLIOGRAPHY	51
Appendix A—Radiation Basics	A-3
Appendix B—Radionuclide Migration and Performance Assessment	B-1
Appendix C—Disposal Technologies	C-1

FIGURES

1.	Commercial low-level radioactive waste disposal facilities	2
2.	Beatty, Nevada disposal site geology	13
3.	Beatty, Nevada, disposal facility map.	14
4.	Maxey Flats, Kentucky, disposal site geology	17
5.	Maxey Flats, Kentucky, disposal facility map	19
6.	West Valley, New York, disposal site geology	24
7.	West Valley, New York, disposal facility map	25
8.	Richland, Washington, disposal site geology	30
9.	Richland, Washington, disposal facility map.	31
10.	Sheffield, Illinois, disposal site geology	35
11.	Sheffield, Illinois, disposal facility map	36
12.	Barnwell, South Carolina, disposal site geology	40
13.	Barnwell, South Carolina, disposal facility map	42
A-1.	Radiation penetration	A-4
A-2.	Natural decay curve of radionuclides	A-6
B-1.	Potential radionuclide migration and exposure pathways	B-3
C-1.	Typical low-level radioactive waste disposal site	C-3
C-2.	Shallow-land disposal	C-5
C-3.	Intermediate-depth disposal	C-6
C-4.	Modular concrete canister disposal	C-7
C-5.	Aboveground vault	C-8
C-6.	Belowground vault	C-9
C-7.	Earth-mounded concrete bunker	C-10

C-8. Earthen-covered abovegrade vault C-11

C-9. Disposal operations C-12

TABLES

1. Volume and activity of waste disposed of at six low-level radioactive waste
disposal facilities 4

Directions in Low-Level Radioactive Waste Management: A Brief History of Commercial Low-Level Radioactive Waste Disposal

INTRODUCTION

As part of the effort by the U.S. Department of Energy's (DOE's) National Low-Level Waste Management Program to develop and make available useful information concerning management of low-level radioactive waste (hereafter referred to as LLW), this report provides a brief history of the development of LLW disposal. It includes early practices and experiences, the development of comprehensive Federal and State regulations, and the enactment of legislation that assigns responsibilities and creates the framework under which LLW management and disposal operations are now carried out. It also contains a summary of the operational histories of commercially operated LLW disposal facilities in the United States.

This examination of the history of LLW disposal practices and of the development of the regulations governing these practices is intended to be instructive and to provide a basic understanding of commercial LLW management in the United States today. To that end, the report has been written for readers who do not have extensive backgrounds in LLW management, but who are interested in its history and in current practices.

Six commercially operated shallow-land disposal facilities have been licensed and operated in the United States (Figure 1). Four of these sites were licensed by State regulatory agencies under agreements with the U.S. Nuclear Regulatory Commission (NRC). The remaining two, located in Washington and Illinois (which had not yet become Agreement States), were licensed by the NRC. Three of the sites have been closed for over 10 years. The sites in West Valley, New York, and Maxey Flats, Kentucky, were closed in 1975 and 1977 respectively, as a result of water management problems. In 1978, the site in Sheffield, Illinois, was closed after the operator experienced lengthy delays with its NRC license renewal. The Beatty, Nevada site closed at the end of 1992 in accordance with an agreement between the Governor of Nevada and the Rocky Mountain Compact Board. The other two disposal facilities (located in Richland, Washington and Barnwell, South Carolina), have operated successfully and continue to receive and dispose of LLW. The experience resulting from the operation of these six disposal facilities was reflected in the issuance of Title 10 Code of Federal Regulations, Part 61, *Licensing Requirements for the Land Disposal of Radioactive Waste* (1983), the Low-Level Radioactive Waste Policy Act of 1980, and the Low-Level Radioactive Waste Policy Amendments Act of 1985.

The report is divided into two parts. Part One discusses the history of LLW management, dividing the information into historical periods and discussing directions for the next decade. Part Two includes individual histories of the six disposal sites. A glossary of terms is included. The appendices provide further information on radioactive decay, radionuclide migration, performance assessment, and disposal technologies. In addition, a reading list has been furnished. The material used in preparing this document was obtained from existing records and reports, State and Federal officials, and site operators. A bibliography is provided at the end of the document.

Figure 1. Commercial low-level radioactive waste disposal facilities.

PART ONE: LOW-LEVEL RADIOACTIVE WASTE DISPOSAL

In the earliest years of the development of nuclear technologies, disposal of radioactive waste by-products was provided by the Atomic Energy Commission (AEC), the predecessor organization to the DOE and the NRC. In the 1950's, several companies had also been licensed to dispose of commercially-generated LLW at sea.

With the growth of commercial applications of nuclear technologies, the AEC announced in 1960 that "regional" land disposal sites for commercially generated LLW should be established by the private sector. The disposal sites would be located on government-owned land (Federal or State) and would be licensed and regulated by government agencies. With the announcement, the AEC indicated that its own land disposal facilities, developed principally for LLW generated through defense activities, would remain available for use by waste generators outside the AEC only until adequate disposal capacity was established in the private sector.

In response to the policy, six commercially operated shallow-land disposal facilities were licensed and operated in the United States (Figure 1). The facilities are located in Beatty, Nevada; Maxey Flats, Kentucky; West Valley, New York; Richland, Washington; Sheffield, Illinois; and Barnwell, South Carolina. The Beatty facility, which opened in 1962, was the first to begin commercial disposal operations; the Barnwell facility, which opened in 1971, was the last. Four of the facilities (Beatty, Maxey Flats, West Valley, Sheffield) have since closed.

The commercially operated LLW disposal facilities have received waste from educational, research, medical, pharmaceutical, and industrial sources, and from nuclear power plants. Most of the LLW received from sources other than nuclear power plants consists of radiologically contaminated paper, packaging material, rags, protective clothing, laboratory glassware, gloves, wood, filters, and failed and obsolete components. Power-plant waste consists of contaminated dry solids, expended filter media, irradiated metal components, and absorbed or solidified liquids. The estimated quantities and radioactivity of the waste disposed of in each site are summarized in Table 1.

Four of the disposal sites were licensed by the Host States under agreements with the NRC. The two remaining sites, in Washington and Illinois, were licensed by the NRC because the States at that time had not become Agreement States. The disposal sites in West Valley, New York, and Maxey Flats, Kentucky, were closed in 1975 and 1977 respectively, as a result of water management problems. In 1978, the Sheffield, Illinois, site was closed after the operator experienced lengthy delays with its NRC license renewal. The lessons learned from the operation of commercial LLW disposal facilities were incorporated in 1983 into a new Federal regulation, Title 10 Code of Federal Regulations, Part 61, *Licensing Requirements for the Land Disposal of Radioactive Waste*.

Since January 1, 1993, the Richland, Washington, facility has accepted LLW only from the Northwest and Rocky Mountain Compact Regions. The Barnwell, South Carolina, facility is scheduled to discontinue accepting LLW from outside the Southeast Compact Region June 30, 1994, and plans to cease operations altogether after 1995.

Table 1. Volume and activity of waste disposed of at six low-level radioactive waste disposal facilities.

Disposal facility	Total waste volume (ft ³)	By-product material (curies) ^a	Source material (lb)	Special nuclear material (lb)
Beatty ^b	4,729,689	640,529	4,035,624	605
Maxey Flats ^c	4,776,836	2,400,690	533,579	952
West Valley ^d	2,467,161	1,262,300	1,035,631	125
Richland ^e	12,537,419	34,363,693	13,478,101	351
Sheffield ^f	3,119,138	60,206	1,085,455	126
Barnwell ^e	24,810,074	7,136,793	33,605,791	6,739

a. These values represent radioactivity at time of disposal; current radioactivity is less as a result of radioactive decay (see Appendix A).

b. Data through 1992 when facility closed.

c. Data through 1977 when facility closed.

d. Data through 1975 when facility closed.

e. Data through 1993.

f. Data through 1978 when facility closed.

Early Practices, 1960–1980

The commercially operated LLW disposal sites adopted shallow-land disposal technologies. These procedures had been commonly used at national laboratories involved in atomic energy research and development and in defense programs that generated radioactive waste requiring disposal. Shallow-land disposal could be used near the locations where the waste was generated, thereby reducing transportation costs. The strategy underlying shallow land disposal was that the natural characteristics of the earthen material in which the waste was disposed would be sufficient to slow the movement of radionuclides until they decayed to background levels through predictable, natural processes. The strategy, however, presupposed that (a) disposal site locations would be selected that provided these kinds of natural barriers, (b) the form of the waste would not allow for easy release of radionuclides, and (c) disposal facility operations would not reduce the safety of the system.

The overall performance of the six LLW disposal facilities has varied from unsatisfactory to very good. Problems were encountered at three of the four sites that have been closed. Most

significant were problems with site instability coupled with difficulties in surface and groundwater management. These problems led to radionuclide migration. Although remedial measures have been taken to avoid exposures to the nearby public, these steps have required expenditures far beyond those originally anticipated to care for and maintain the sites. The instability experienced at the sites has also made prediction of long-term performance of these sites difficult. Experience at these sites indicates that a combination of unstable waste forms, specific site characteristics, and certain design and operational practices led to problems with water management and site instability. There were also problems with respect to financial assurance and institutional control of the sites.

Inadequate waste form was one of the most significant factors leading to the problems. Waste forms sent to the disposal sites reflected general practices of the times. Licensees were encouraged to send all suspect wastes for disposal. Because waste disposal was inexpensive, there was little incentive for waste generators to minimize the amount of waste produced or to compact the material into a more stable waste form. Most of the waste that was disposed of at the sites is believed to have been either composed of very easily degradable material or packaged so that large void spaces existed within the waste or between the waste and the packaging. Some of the waste packages (such as cardboard and fiberboard boxes) were easily degradable. Also, the wastes often contained chemical agents that enhanced waste degradation and leaching of radionuclides. Frequently, these easily degraded wastes contained little or no radioactivity.

As the waste material degraded and compressed, a process which was accelerated by contact with water, additional voids were produced. These voids led to settlement of the disposal trench contents, followed by subsidence or slumping of the disposal trench covers, which in turn routed surface water into the disposal trenches and accelerated the degradation cycle. In many cases, the soil in which the trenches were dug was less permeable to water than the soil which was used to cover the trench. This difference in permeability allowed the trenches to fill with water, a phenomenon known as the "bathtub" effect.

Early operating practices also contributed to rapid waste degradation, subsequent slumping of the trench covers, and the entry of water into the disposal units. Waste was placed within the disposal trenches with little or no attempt to segregate waste types according to their characteristics (such as chemical content or the relative stability of the waste packages). In general, little compaction was applied to the disposed waste, backfill, and trench covers other than that provided by driving over the disposal trenches with heavy trucks. Thus, considerable void spaces probably existed within the trenches, promoting rapid settling. At the humid sites, water from rainfall was frequently allowed to accumulate in the open disposal trenches while they were being filled, again promoting rapid waste degradation and settling.

The characteristics of several of the disposal site locations also contributed to the problems. Low-permeability soils retained the water that had entered the disposal units, allowing it to become contaminated with radionuclides before its slow release. "Sand lenses," thin, isolated layers of sand underground, served to route groundwater into the disposal trenches. In one case, a permeable layer at the level of the bottom of the trenches helped conduct contaminated water away from the trenches and offsite.

Problems of this magnitude and type have not been experienced at the two sites still in operation and the recently closed Beatty, Nevada site. The Richland, Washington site and the Beatty site are in arid or semi-arid environments and do not experience water management problems. The site at Barnwell, South Carolina, which is in a humid environment, has not experienced water management problems for a number of reasons. Since the Barnwell facility was the last to open, the site benefitted from the experiences of the other sites. Specifically, the cap covering the disposal trenches is specially designed to minimize water infiltration. Surface sand layers surrounding the trenches are removed and compacted clay is added. The trenches have sumps for sampling purposes and monitoring trench water levels that may also be used to remove accumulations of water, if necessary. Attention to surface water management has been a key element in providing drainage away from trench areas and collection basins for surface run-off. As discussed in Part II of this report, elevated tritium levels have been detected in shallow groundwater monitoring wells in the Barnwell facility. However, tritium levels in on-site monitoring wells are well below the Federal Primary Drinking Water Standard for tritium.

The two currently operating disposal sites and the recently closed Beatty, Nevada site did, however, have operational problems unrelated to site performance. In one incident, slightly contaminated hand tools shipped for disposal as LLW were removed from waste packages by site workers and taken off site. In the fall of 1979, after a series of incidents involving improperly packaged waste and damaged waste containers, the governors of Nevada and Washington temporarily closed the sites in those States. The governor of South Carolina, with the only operating disposal site in the east, began a 2-year phase-down of the volume of waste accepted at the Barnwell site to 1.2 million ft³/yr. Although these actions were taken primarily to protect public health and safety, the governors also intended to demonstrate the need for more stringent enforcement of LLW regulations, and to signal their States' dissatisfaction with their status as hosts for the Nation's only disposal sites.

Regulatory Reform, 1980-1985

The problems experienced in the developmental years of commercial LLW disposal led to the recognition that the regulations controlling the licensing of radioactive materials did not contain sufficient technical standards or criteria for the disposal of LLW. More comprehensive standards, technical criteria, and licensing requirements were needed for the selection of disposal site locations, the form and characteristics of waste allowed for disposal, and operational practices.

In December 1982, the NRC added a new part to Title 10 Code of Federal Regulations: Part 61, *Licensing Requirements for Land Disposal of Radioactive Wastes* (10 CFR 61). This regulation established a series of performance objectives and technical and financial requirements which a low-level radioactive waste disposal site and site operator must meet in order to ensure public health, safety, and long-term protection of the environment. The regulation established four performance objectives: (a) to protect the general population from releases of radioactivity, (b) to protect any individual who inadvertently enters a disposal site after the site is closed, (c) to protect workers during site operations, and (d) to ensure long-term stability at disposal sites to eliminate the need for ongoing active maintenance after closure.

Technical requirements were established for site selection, design, operation, closure, environmental monitoring, and waste classification and characteristics. These included: (a) sites must have characteristics that maximize long-term stability and isolation of waste and ensure that performance objectives are met (site characteristics and performance must be evaluated for at least a 500-year period); (b) sites chosen for LLW disposal must be capable of being characterized, modeled, analyzed, and monitored; (c) the facility must be designed to provide for long-term isolation of the waste while minimizing the need for active maintenance after the site is closed; (d) monitoring systems must be capable of providing early warning of releases of radionuclides before they leave the site boundaries; and (e) to reduce subsidence or cracking of the caps or barriers covering the waste, all LLW must be placed in the disposal unit in a way that maintains the integrity of the waste package and permits voids to be filled.

Special technical requirements were also established for waste form. These requirements included: (a) waste must not be packaged for disposal in cardboard or fiberboard boxes; (b) liquid waste must be solidified or packaged in absorbent material; (c) wastes that generate toxic fumes or are spontaneously flammable or explosive are prohibited; (d) waste form or high integrity containers used to provide structural stability must maintain gross physical properties and identity for 300 years, under the expected disposal conditions; and (e) void spaces must be reduced to the extent practicable. A waste classification system, based on the concentration of longer lived radionuclides, was also established as part of the regulation. Different disposal standards are prescribed for the three different classes of waste, Class A, Class B and Class C. A 1985 Federal law made the Federal government responsible for disposal of any LLW that exceeds Class C limits.

The three States with operating disposal sites at that time also issued regulations to ensure that the transportation and packaging problems they had experienced would not be repeated. In general, these State regulations required radioactive waste shippers to (a) purchase transportation permits and liability insurance, (b) certify that the shipment and transport vehicle have been inspected and comply with applicable State and Federal laws, and (c) notify the disposal facility prior to shipment of waste. The regulations allowed for the imposition of fines ranging from \$1,000 to \$25,000, and suspension or revocation of shipping permits for serious or repeated violations.

Since the early 1980s, the NRC and Agreement State agencies have issued numerous guidance documents that elaborate on the basic requirements in the regulations. These guidance documents address specific techniques for evaluating whether a proposed disposal system (site location, facility design, waste form and operational practices) will be sufficient to protect the environment and public health and safety.

Although not part of the Federal regulatory requirements, there has also been a movement toward disposal systems that incorporate engineered barriers (generally waste packages or disposal cells constructed of low-moisture concrete). The primary purpose of these human-made barriers is to reinforce public confidence that the waste will be safely isolated from the environment while it decays to background levels. The long-term benefits of engineered barriers over carefully selected natural barriers has been a topic of much discussion and technical analysis. For example, in some locations the groundwater has not moved very far in thousands of years, indicating that any radionuclides that migrate from a disposal unit are unlikely to travel far before undergoing

natural decay. In such an environment, a human-made barrier would add little protection. Nevertheless, the selection of multiple barrier systems illustrates the degree to which State and compact region officials have responded to public concerns that disposal of LLW should pose as little risk to public health and safety as reasonably possible.

Lessons learned during the developmental years of commercial LLW disposal led to regulatory reform of the system under which disposal is conducted. Improvements in the form of waste that is disposed, as well as in site selection, characterization, operations, monitoring and postclosure care, have significantly reduced the likelihood that a new LLW disposal facility will require costly remediation in the future.

State Involvement, 1980–1994

By 1980, it appeared that private industry would not be able to develop new disposal facilities without the participation of government, in spite of the regulatory reforms that were underway at the time. In December of that year, Congress passed the Low-Level Radioactive Waste Policy Act (PL 96-573). The law was designed to restore the "regional" approach to LLW disposal that had evolved in the previous two decades. The law encouraged States to form regional compacts for disposal of LLW and provided that such compacts, if approved by Congress, would be able to limit use of their disposal sites to LLW generated within their respective regions, beginning January 1, 1986.

At the time the 1980 law was enacted, the National Governors' Association, the National Conference of State Legislatures, and the State Planning Council (a study group that included State and local officials), and other groups supported State responsibility for disposal of LLW. These groups believed that State participation in the development of new disposal facilities for LLW disposal would allow better public oversight than would be the case if the private sector alone, or the Federal government, were assigned responsibility to establish new disposal sites.

It took several years following enactment of the 1980 Act for States to form compacts. Because it had become apparent that the network of new disposal facilities would not be established by 1986, Congress hesitated to ratify the compacts that had been introduced. Following a compromise negotiated between the compact regions with operating disposal sites, and the States and regions without disposal sites, Congress in 1985 amended the 1980 Act. The new law gave congressional approval to the seven original compacts—Central, Central-Midwest, Midwest, Northeast, Rocky Mountain, Southeast, Northwest—but required the three regions with operating disposal facilities to continue accepting waste from outside their regions through 1992. In subsequent congressional sessions, two additional compacts, the Appalachian and the Southwestern, were given congressional approval.

Although the steps in establishing a new disposal facility are essentially the same as they were in the early days of site development (site selection, site characterization, license preparation, license review, operations, closure and postclosure maintenance), each of these steps today is far more extensive and is conducted under much closer public scrutiny. In addition to the general requirements in 10 CFR 61, States have established site requirements based on Federal regulations, and supplemented, in some cases, by additional State requirements.

States have flexibility as to the approaches or methods they use in selecting disposal sites and in the design of disposal facilities. The States designated as Host States for compact regions, and unaffiliated States developing new disposal sites have adopted a variety of approaches to meet the objective.

In most cases, the States assigned responsibility for disposal site selection and development to existing agencies of government or created new agencies and quasi-State agencies to head the projects. In two regions, the Central Compact Region (Nebraska) and the Southwestern Compact Region (California), a private sector approach was adopted. In these regions, responsibility for siting and developing the new facilities was delegated to firms in the private sector through contract mechanisms, subject, of course, to State licensing and regulation. The following table summarizes the organizational approaches that have been adopted by the Host States:

California	Private sector firm using its own investment capital, under contract to State agency
Connecticut	Existing independent State agency
Illinois	Existing State agency
Maine	New quasi-State authority
Massachusetts	New quasi-State authority
Michigan	New independent authority within existing agency
Nebraska	Private sector firm under contract to Central Compact
New Jersey	New quasi-State authority
New York	New quasi-State authority to site facility; existing State agency to develop and operate
North Carolina	New quasi-State authority
Ohio	Evaluating options
Pennsylvania	Existing State agency
Texas	New quasi-State authority
Vermont	New quasi-State authority.

The Host States have varied, too, in their approaches to site selection. Only in Connecticut and Vermont did State law require that a specific site selection method, a "top-down screening" approach, be used. Although not required by law, siting organizations in most of the other States, however, adopted this particular approach.

In top-down screenings, mapping processes were used to eliminate large tracts of land from further consideration or to focus site selection on areas that appear more likely to include suitable site locations. For purposes of efficiency, the screenings generally used a phased approach, first applying data that was readily and uniformly available across the entire study area. By first eliminating areas that appear from the data to be less likely to have suitable site locations, subsequent phases of the screening, for which data is more difficult to obtain, were focused upon smaller land units. Upon exhausting all available data that can be applied in a map screening process, area visits by teams of specialists were usually necessary in order to identify local features that might qualify or disqualify specific areas.

Although these "top-down" screening techniques appeared to provide a scientifically-driven way to select a small tract from within a large study area, data limitations and problems in their practical application have been a root cause of controversy in most of the States that have used these methods. This has been due, in part, to imperfections in the data available for screening at the State and regional level. For example, an incorrect depth to bedrock for a specific location might be assumed from a single measurement taken somewhere in the vicinity. Or, standard maps showing perennial streams might differ in the location of the streams, or whether or not they are really "perennial." The disparity between the popular perception of top-down screening processes as scientifically rigorous versus the realities involved in their practical application resulted in litigation, investigations and legislative intervention.

To avoid these kinds of problems, Illinois and the Central States Compact (in Nebraska) limited their site screening exercises to only those counties that initially expressed interest in participating. However, where volunteer approaches have been used that emphasized the benefits and incentive of hosting the proposed facilities, some charged that siting officials were attempting to "bribe" the communities into accepting the facilities. The Illinois Siting Commission, for example, criticized the siting organization's efforts to promote the idea of hosting the facility in the local community. Yet, current academic literature on methods for siting controversial facilities leans heavily in favor of such voluntary methods.

Once a preferred site is identified for further evaluation, "site characterizations," or detailed field investigations and analysis, are conducted to develop information for the license application. License applications are submitted to the NRC, or to a State regulatory agency in States that have agreements with the NRC to regulate radioactive materials. The license application must demonstrate that the facility will be able to isolate the waste while it decays to near background levels. This is done through mathematical calculations that take into consideration the characteristics of the site location, the facility design and the waste to be disposed. The license application also describes plans for environmental monitoring of the site both during and after the operational period. Information is also provided on ecological characteristics, such as threatened or endangered species, and on cultural resources, land use considerations, and socioeconomic impacts, as well as information on the financial status of the applicant.

Review of the license application is an extensive process. In 1988, the NRC estimated that its review of a license application would require a minimum of 416 staff-weeks across 21 different disciplines (NUREG-1274, August 1987).

Thus far, license applications for new facilities have been submitted in California, Illinois, Nebraska, North Carolina, and Texas. The Martinsville alternative site was rejected in Illinois by a special State commission not associated with the licensing agency, and the technical review of the license application was not completed. In California, the application was approved by the Department of Health Services and an operating license issued, but construction of the facility has been delayed until the Federal land on which the site is located can be transferred to the State. In the other three States, the applications are still under review by State agencies.

PART TWO: HISTORIES OF SIX LOW-LEVEL RADIOACTIVE WASTE DISPOSAL FACILITIES

Beatty, Nevada

The Beatty LLW disposal facility was the first commercially operated radioactive waste disposal facility to be licensed by the U.S. Atomic Energy Commission (AEC), now the NRC. The Beatty site is located on the Amargosa Desert in Nye County, on land owned by the State of Nevada. The disposal site is on an 80-acre tract approximately 11 miles south of the town of Beatty and 105 miles northwest of Las Vegas.

Site Description

The Amargosa Desert region where the site is located is part of the Basin and Range Province, which is characterized by relatively barren mountain ranges and broad, relatively flat valleys. The site is located on unconsolidated deposits of alluvial sand, clay, silt, and gravel approximately 600 ft thick, formed by weathering action on the adjacent mountain ranges (Figure 2). Underlain at depth by folded metamorphic and sedimentary bedrock, the site surface is approximately 2,800 ft above sea level. A regional groundwater table lies at a depth between 260 and 330 ft below the surface in the alluvial soils.

An intermittent river, the Amargosa River, lies five miles from the site and serves as the principal drainage channel in the area. There is no source of perennial surface water within 10 miles of the site.

The climate at the site is arid, with an average annual rainfall varying from 2.5 to 5 in. and a potential evaporation rate of approximately 100 in. per year.

The LLW disposal facility is located next to a chemical waste disposal facility. A buffer zone, a minimum of 200 ft wide, and a security fence separate the two facilities.

The LLW disposal site consists of 22 trenches of varying dimensions, ranging from 300 to 800 ft long, 4 to 350 ft wide, and 6 to 50 ft deep (Figure 3). The trenches constructed in recent years have tended toward the larger dimensions.

Operating History

The Beatty facility opened in September 1962 and operated until December 31, 1992. The first licensed operator of the site was California Nuclear, Inc. In March 1968, the assets of the company were transferred to Nuclear Engineering Company (NECO), which in 1981 changed its name to US Ecology, Inc. US Ecology is the site operator today.

LLW was disposed of at Beatty primarily by shallow-land burial. Trenches were constructed with conventional earth-moving equipment, following a cut-and-cover procedure. Because of the high stability of the local soil, trenches were typically cut with nearly vertical side slopes, maximizing the space available for waste disposal. Waste packages were generally emplaced in an

R94 0615

Figure 2. Beatty, Nevada disposal site geology.

This map is an artist's rendering from inexact input and is therefore not accurate as to measurements and distance.

R94 0544

Figure 3. Beatty, Nevada, disposal facility map.

orderly manner, using either a crane or forklift. Waste-transport vehicles were driven down ramps and the waste was unloaded directly into the larger trenches. In the older trenches, waste was placed in the trench to within 3 ft of the ground surface. In the more recently excavated trenches, the waste was placed at least 8 ft below ground surface. The trench cover was mounded over the waste to a vertical centerline elevation of at least 2 ft above the surrounding ground surface. Thus, the center surface of the trench cover is at least 10 ft above the waste. The completed trenches are identified by permanent concrete posts marked with the trench number, dates opened and closed, trench boundary coordinates, and waste characteristics (i.e., total volume and activity, as well as the quantity of source and special nuclear materials). Trench boundaries are located by an engineering survey referenced to benchmarks.

From startup in 1962 through 1992, over 4.7 million ft³ of waste was buried at Beatty (Table 1). This waste contained about 640,000 curies of by-product material, 4.0 million lb of source material, and 605 lb of special nuclear material.

There have been no significant problems with environmental performance of the disposal facility. Difficulties that were experienced were unrelated to the ability of the site to isolate LLW. Problems were encountered in 1976 when it was discovered that site employees had removed a cement mixer and various tools, hardware, and building materials which had been brought on site as radioactive waste. These materials were used by the site employees in local construction projects. The NRC and State of Nevada suspended US Ecology's operating license until the contaminated materials were recovered and residual radioactivity was removed. The company terminated all the employees who were responsible for the violations and a new site manager was brought in to manage Beatty.

Between March 1976 and December 1979, a series of events involving improper handling and packaging of LLW resulted in the closing of the site for intervals because the operator's license was temporarily suspended. The site was reopened only after assurance was given by the Federal Government that the rules governing shipments of LLW would be enforced. At the same time, a permitting system for waste shipments was established.

Additional regulatory and license requirements, implemented as a result of the operational difficulties previously encountered, tightened both State and operator management controls. A third-party inspection system was implemented in April 1981, which all generators shipping to Beatty were required to accept as a condition for receiving a permit to use the disposal site. Administrative fines of up to \$20,000 per incident, suspension of permits, and criminal penalties could have resulted from permit infractions.

Nevada became a member of the Rocky Mountain Compact Region in 1985. As one of the three sited States at the time, Nevada was obligated to allow the Beatty facility to dispose of wastes generated outside the compact through 1992, as long as the States in which the generators were located continued to meet the milestones prescribed in the Low-Level Radioactive Waste Policy Amendments Act (LLRWPA) of 1985. The LLRWPA of 1985, however, limited the amount of waste Beatty was required to accept to 1.4 million ft³ during the 7-year period of 1986-1992 (based on an average annual volume of 200,000 ft³ per year).

Facility Status

The Beatty disposal facility closed on December 31, 1992, in accordance with an agreement between the Governor of Nevada and the Rocky Mountain Compact Board. The Compact Board had designated Colorado to assume responsibility for the Compact Region's LLW disposal. However, in 1992 the Rocky Mountain Compact Board entered into an agreement with the Northwest Compact Commission that allows LLW generators in the Rocky Mountain Compact Region to dispose of their waste at the Richland facility.

US Ecology, Inc. has submitted and the State of Nevada has approved a site stabilization and closure plan for the Beatty disposal facility. The closure plan provides site-specific requirements to ensure that the facility is closed in accordance with the radioactive material license and the lease agreement between the State of Nevada and US Ecology, Inc. The purpose of the plan is to ensure that the waste disposed of during the operational phase of the facility continues to remain in a suitable, stable, and safe condition after site closure. US Ecology began implementing the site stabilization and closure plan on December 31, 1992. The plan includes constructing a cap over the trenches, which is currently expected to be completed in late 1994. Following the completion of the cap and 9 additional months of monitoring, the site will be transferred to the Nevada Department of Lands.

The Beatty site operator, US Ecology, Inc., and the State of Nevada monitor the concentrations of radioactivity in groundwater in both onsite and offsite wells and in air, soil, and vegetation on a quarterly basis. Records of the measured concentrations are maintained. This monitoring has not shown evidence of any significant migration of radioactivity from the disposal trenches through any environmental pathways.

Maxey Flats, Kentucky

The Maxey Flats LLW disposal site is located about nine miles northwest of Morehead, Kentucky, 65 miles northeast of Lexington, Kentucky, and 200 miles southeast of Cincinnati, Ohio. The 280-acre site is owned by the Commonwealth of Kentucky. The site was opened under a lease arrangement between the State of Kentucky and Nuclear Engineering Company (now US Ecology, Inc.), of Louisville, Kentucky in January 1963. US Ecology, Inc. operated Maxey Flats until December 1977, at which time commercial operations were terminated. The disposal site has remained closed since that date.

Site Description

Surface soils at the site generally consist of light-brown silty clay, ranging in depth from 1 to 10 ft. In most areas of the disposal site, this cover layer is terminated by a thin layer (18 to 24 in.) of siltstone or very fine sandstone, which is directly underlain by shale, siltstone, and sandstone (Figure 4). The trenches lie entirely within the Nancy member of the Borden Geologic Formation. The Nancy member is a green shale that manifests plastic behavior when wet, and which is interbedded with siltstone and sandstone. It is an aquitard, having low permeability, and contains isolated groundwater in the soil zone at a depth of 3 to 6 ft. There is a continuous groundwater table at a depth of 30 to 50 ft, but no regional aquifer is present in the area. Groundwater migration occurs primarily through shale fractures and interlinking sandstone beds.

R94 0611

Figure 4. Maxey Flats, Kentucky, disposal site geology.

The ridge area where the site is located slopes off sharply on three sides. The area is drained on three sides: to the east by a perennial stream, No-Name Creek, which collects about 75% of the surface runoff; to the west by Drip Springs Hollow Creek, and to the south by Rock Lick Creek. The drainage from these tributaries flows into Fox Creek and then into the Licking River. The site is in a humid region, with rainfall varying by season, but most abundant in spring and early summer. The average annual rainfall in the region is 46 in.

The disposal site currently consists of 52 trenches, a number of hot wells (disposal caissons), and several special pits (Figure 5). The trenches vary considerably in size, ranging from 150 to 680 ft long, 10 to 75 ft wide, and 9 to 30 ft deep. The floor of each trench slopes at one degree toward a sump constructed at the low end to permit water collection and removal. The hot wells are lined, variable in size (generally 15 ft deep and several ft in diameter) and capped with concrete. The hot wells were used to dispose of high-activity gamma sources. The special pits, which vary from 15 to 75 ft long, 9 to 25 ft wide, and 5 to 15 ft deep, were used to dispose of large volumes of higher activity waste, such as spent resins from power reactors.

Operating History

Maxey Flats was opened as a commercial disposal site to service the growing nuclear utility and industrial waste-generation market in the southeast and mid-Atlantic States, and as a vehicle for Kentucky to encourage a commercial nuclear energy program.

Trenches were excavated to full size before emplacement of waste containers began. After being logged in and surveyed, the waste containers were placed into the trench, beginning at one end. A crane was used to emplace large items and those packages having high surface radiation levels. When the trench was filled with LLW, it was covered with a minimum of 3 ft of clayey soil, applied in compacted layers. A mounded cap was developed over each trench to enhance water runoff, and a layer of topsoil (2 to 3 ft) was added to support a vegetative cover. The completed trench was marked with a monument, placed at one end, on which the trench number and date of closure were recorded. Disposal records locating the trench boundaries and providing data on total volumes and radioactivity content of the trench are keyed to the monument. However, recent work at the site indicates that disposal records and trench monuments are not always accurate.

Before it was closed, Maxey Flats became the largest commercial repository for LLW in the nation, and still contains a significant fraction of all the commercially generated LLW buried in the United States. During the period between startup in 1963 and closure in 1977, over 4.7 million ft³ of waste were buried at Maxey Flats (Table 1). This waste contained about 2.4 million curies of by-product material, 533,000 lb of source material, and 950 lb of special nuclear material. Tritium (H-3) was probably the most abundant radionuclide in the trenches (see discussion on radioactive decay in Appendix A), although site records are not sufficiently complete to permit an exact determination. This study estimates that 176 lb of plutonium-239 (relatively evenly distributed across the entire volume of the waste), plus other plutonium isotopes, were buried at the site.

Subsidence, water management problems, and the resulting migration of radioactivity in the area of the site caused a growing public and official concern through the early to mid-1970s. In

R94 0608

Figure 5. Maxey Flats, Kentucky, disposal facility map.

the early 1970s, a significant amount of water accumulated in the disposal trenches. This water accumulated as a result of both a high rate of precipitation and a greater rate of infiltration into the trenches than out of them, the "bathtub" effect. In 1973, Kentucky required Nuclear Engineering Company to initiate a water management program. This program, conducted first by the Nuclear Engineering Company and later by the Commonwealth, continued until mid 1980. The program involved pumping the contaminated water from the trenches to aboveground holding tanks, treating the water to remove radioactivity, evaporating the treated water, and transferring the residual material to storage tanks to hold for eventual disposal. The evaporator effluent, although controlled by dilution of trench liquid to ensure that environmental releases were below allowable NRC standards, represented a source of offsite radioactivity because it contributed to surface contamination through dispersal of the plume in the vicinity of the site. Furthermore, site management and disposal practices in the operating period before 1972 probably contributed other potential sources of surface contamination from accidental spillage of waste, direct disposal of contaminated liquids on the slopes of the site, and dispersal of liquid from the trenches by earth-moving equipment.

Basis for Facility Closure

The site was ordered closed by the Commonwealth in December 1977 after it was discovered that trench leachate was seeping laterally into an adjacent, newly constructed trench. This flow was along a thin siltstone bed about 25 ft below ground surface. This bed formed the bottom of most of the trenches and was serving as a conduit for leachate migration from the site.

Postclosure History

In May 1978, the Commonwealth, after negotiating the purchase of the site operator's leasehold right and equipment, assumed control of the site. The Kentucky Finance and Administration Cabinet was placed in charge of stabilizing the facility. In February 1979, the Finance Cabinet delegated to the Natural Resources and Environmental Protection Cabinet the responsibility of managing the site.

Postclosure maintenance of the site was performed by US Ecology, Inc., under contract with Kentucky until 1979, at which time National Waste Management Services of Lexington, Kentucky, a subsidiary of Dames & Moore, Inc., was selected to maintain the site. National Waste Management Services continued to provide the necessary support services at Maxey Flats through June 1981 to maintain the site in its shutdown state. Kentucky then selected Hittman Nuclear Development Corporation of Columbia, Maryland, to maintain the closed site. Westinghouse Electric Corporation is currently under contract to Kentucky to maintain the site.

Improvements in maintenance operations were undertaken at the facility to reduce the likelihood that water would contact the buried waste. In late 1981, a flexible membrane liner was installed as a surface cover over the trench area and associated surface drains to direct as much surface water away from the trenches as possible into defined surface drainage ways and then off site. This action significantly reduced radioactive material release from the site due to surface influences. Other actions included grading and improving surface drainage, recapping older trenches to reduce permeability, and improving procedures for capping new trenches. According

to one Kentucky official, these efforts, plus the removal of several areas of surface contamination, appear to have been effective in reducing the release of radioactivity.

Routine environmental monitoring and special investigations during this period revealed elevated levels of tritium in the surface water, groundwater, and vegetation from the west hillside of the Maxey Flats Disposal Site. In particular, two trees which had much higher than normal concentrations of tritium in their leaves were identified on the west hillside. In 1983, the Kentucky Cabinet for Human Resources undertook a program to identify the source of the tritium in the trees on the west hillside. The results of the investigations demonstrated that trench leachate had moved from the trenches to the west hillside along the lower siltstone bed. Sampling indicated that the leachate was present outside the controlled area and presented a potential for both pollutants and radionuclides to migrate from the site to the local environment. In consideration of the potential health impacts the migration might present, a decision was made to pursue remediation via the Environmental Protection Agency (EPA) Superfund process.

Facility Status

In 1986, the EPA notified 832 parties that Maxey Flats had been designated a Superfund site. Each of these parties was designated a Potentially Responsible Party in any corrective actions. These parties include Federal agencies, Federal contractors, medical facilities, physicians, clinics, industry, State agencies, transporters, broker/haulers, and the land owner and site operator.

In 1988, EPA conducted a two-phase removal action to handle the threat posed by 11 onsite 20,000-gal tanks of questionable structural integrity located in a tank farm building. Phase I consisted of installing a heater in the tank farm building to prevent freezing and rupturing of tank valves and fittings. Phase II consisted of solidifying approximately 286,000 gal of radioactive liquids stored in the 11 tanks and water on the floor of the tank farm building. The solidified blocks were disposed of onsite in a newly constructed trench.

A Remedial Investigation and Feasibility Study (RI/FS) was completed in 1991. The RI/FS characterized the nature and extent of contamination at the site and evaluated remedial alternatives. A Record of Decision was issued by the EPA on September 30, 1991, which identifies the selected remediation approach.

The selected remedial action for the site includes

- Extracting, solidifying, and disposing onsite approximately 3,000,000 gal of trench leachate
- Demolishing and disposing of site structures onsite
- Excavating additional disposal trenches for disposal of site debris and solidified leachate
- Installing an 50-acre initial cap consisting of a clay and synthetic liner after disposal of solidified leachate and debris in the trenches

- Maintaining and periodically replacing the initial cap synthetic liner as needed every 20 to 25 years
- Re-contouring the capped disposal area as needed to enhance the management of surface water run-on and run-off
- Temporarily storing any additional wastes generated after constructing the initial cap onsite, followed by solidification and onsite disposal of those wastes in a newly constructed disposal trench
- Installing a groundwater flow barrier, if necessary
- Installing an infiltration monitoring system to continuously verify remedy performance and detect the accumulation of leachate in disposal trenches
- Installing a final engineered multi-layer cap once natural subsidence of the trenches has nearly ceased, which could take 100 years
- Installing permanent surface water control features
- Monitoring soil, sediment, surface water, groundwater, leachate, air, selected environmental indicators, and rates of subsidence
- Procuring a buffer zone adjacent to the site to prevent deforestation or erosion of the hill slopes, which could affect the integrity of the selected remedy, and to provide an area for monitoring
- Implementing institutional controls including land use restrictions.

The cost in 1991 for this remedial action was estimated to be \$33,500,000, which includes an Operation and Maintenance cost of \$10,097,549. A statement of work for implementation of the Record of Decision is nearly complete and the EPA, Commonwealth of Kentucky, and the Potentially Responsible Parties are currently negotiating a Consent Decree. The Consent Decree is a legal document that specifies how the Record of Decision will be implemented and outlines the responsibilities of the Potentially Responsible parties including financial obligations. Negotiations on the Consent Decree should be completed in 1994.

West Valley, New York

The Western New York Nuclear Service Center was established in 1962 to encourage development of nuclear technologies in the northeast United States. The major facilities at the Nuclear Service Center include: (a) the only commercial nuclear fuel reprocessing plant that ever operated in the nation; (b) a spent fuel receiving and storage facility; (c) a high-level liquid waste storage facility; (d) a 7-acre waste disposal ground licensed by the NRC and used primarily to dispose of solid, long-lived waste such as spent fuel hardware; and (e) a commercial LLW disposal site. The LLW facility is licensed by the New York State Department of Labor and is also

regulated by the New York State Department of Environmental Conservation. This report addresses only the commercial LLW waste disposal site.

The Nuclear Service Center is a 3,345-acre site located about 30 miles southeast of Buffalo, New York, in a rural area near the small community of West Valley. The West Valley disposal site, opened as a commercial venture in 1963, was operated by Nuclear Fuel Services under a lease arrangement with the State of New York until March 1975. At that time, operations were suspended after an overflow of contaminated water (trench leachate) was detected from two of the disposal trenches. The disposal site has remained closed since that date. In February 1982, the DOE took possession of most facilities at the Center for the purpose of carrying out the West Valley Demonstration Project. The State-owned commercial LLW disposal site is currently under the custody of the New York State Energy Research and Development Authority (NYSERDA).

Site Description

The disposal facility is located on a plateau near the middle of the Nuclear Service Center. The location of the disposal site was selected because of its good surface drainage, the absence of any near-surface aquifers, and the low permeability and high adsorptive capacity of its soil. The soil where the disposal area is located (Figure 6) consists of a top layer (10 to 12 ft) of weathered till (which is a brown, firm, silty clay containing bits of gravel and rock) overlying a layer (150 to 300 ft) of unweathered till (a gray, plastic, silty clay having scattered rock fragments and pebbles). An Upper Devonian Shale of the Canadaway Group is the bedrock underlying the tills at the site. It is a moderately hard shale and siltstone which may attain a thickness of 500 ft or more beneath the disposal area. The surface water in the vicinity of the disposal area consists of Frank's Creek on the east side, Erdman Brook on the north side, and an unnamed tributary on the northwest side, which join to the northeast of this area.

The site consists of two distinct sets of parallel trenches, identified as the north and south disposal areas (Figure 7). The northern area, used during the 1963 to 1969 time period, consists of five long trenches numbered 1 to 5 and two "special" trenches numbered 6 and 7. Trenches 1 through 5 are nominally 30 ft wide, 20 ft deep, and 600 ft long. The distance between trenches is 4 to 6 ft; however, due to the method of construction (bulldozer excavation) and instances of wall collapse, some trenches are believed to be connected. The trenches were originally covered with a 4-ft soil cap; in 1978 an additional 4 ft of soil cover was added. Trench 7 is a narrow, shallow concrete vault in which wastes were disposed and trench 6 is actually a series of holes for the disposal of wastes with high surface radiation readings, which required immediate shielding upon receipt at the disposal site.

The southern area was developed between 1969 and 1975. This area also consists of seven trenches (numbered 8 to 14) that are typically 30 ft wide, 20 ft deep, and 600 ft long. During development of this area, a number of changes in construction and disposal practices were incorporated as a result of the experience gained from the northern area. Among other things, the separation distance between trenches was increased to 10 ft, trench floors were sloped, and cap thickness was increased to 8 ft. Waste was emplaced beginning at the shallow end of the trench and proceeding to the deeper end. This allowed precipitation which entered the trenches during construction and filling to drain away from the waste and collect at the lower end of the trench. During operations, the infiltrate was pumped to two lagoons located adjacent to the

R94 0610

Figure 6. West Valley, New York, disposal site geology.

This map is an artist's rendering from inexact input and is therefore not accurate as to measurements and distance.

R94 0542

Figure 7. West Valley, New York, disposal facility map.

northern trenches. These lagoons are now filled with soil. A third lagoon for pumped-out trench water was constructed next to the southern trenches in 1975. This lagoon was filled with soil over a liner in 1991.

Operating History

The 22-acre commercial LLW disposal site was established as a natural outgrowth of other nuclear activities. It satisfied the need for disposal capacity for the nuclear facilities, industries, and institutions that generated solid radioactive waste in the northeast and mid-Atlantic States, and at the same time provided disposal capacity for LLW generated by the nearby reprocessing plant.

The disposal trenches were excavated in segments as needed, depending on the rate of waste accumulation. The waste containers were placed in the trenches primarily by hand except for heavy containers or those with high surface radiation levels, which were emplaced by means of a crane. After each section of a trench was filled, it was covered with soil, initially to a minimum cap thickness of 4 ft and, after 1968, to a minimum thickness of 8 ft. Trenches numbered 1 through 7 had 4 ft of cap cover until 1978, when an additional 4-ft cover was added.

Disposal records indicate that, during the years the disposal facility operated, about 2.5 million ft³ of waste were disposed (Table 1). This waste contained about 1.3 million curies of by-product material, 1 million lb of source material, and 125 lb of special nuclear material. Tritium (H-3) was the most abundant radionuclide present, with a total of 106,000 curies being buried (see Appendix A for a discussion of radioactive decay). Of the special nuclear materials accepted for disposal, approximately 35,000 curies of plutonium-238 were disposed before the State stopped this practice in 1973.

Basis for Facility Closure

Routine monitoring of the disposal trenches showed that water had accumulated in the trenches during the first 2 to 3 years after each trench was covered and then remained constant, with the exception of Trenches 3, 4, and 5. The water in Trenches 3, 4, and 5 continued to rise until March 1975, when it reached the original soil surface level and seeped through the covers of Trenches 4 and 5, flowing at a rate of approximately 1 gal per day.

Nuclear Fuel Services stopped disposal operations when the seepage was discovered and agreed that disposal operations would not resume until all New York State Department of Environmental Conservation requirements for reopening the disposal area were met. No waste has been buried in this facility since that time, although subsequent corrective measures have been taken to minimize the amount of water infiltrating into the trenches.

Postclosure History

Following a study of the trench water problem and possible corrective actions, a trench cap rehabilitation program was conducted. Based on experience with the southern trenches, it was believed that 8-ft-thick trench caps would prevent infiltration of water. Consequently, in the

summer of 1978, an additional 4 ft of compacted silty till was placed on top of Trenches 1 to 5 and surface drainage improvements were made.

Shortly after the trench cap rehabilitation, sharp increases in water levels in Trenches 11 to 14 in the south disposal area were measured. These increases were attributed to an extended dry summer period that caused desiccation cracking in the cover. Corrective actions, taken in the fall of 1980, included removing 24 in. of till and 6 in. of topsoil from the trench covers, placing and compacting a new 28-in. layer of till in sublayers, and adding 12 in. of topsoil. This work was followed by pumping the accumulated water from the trenches, and was completed in the spring of 1981.

In December 1980, the Nuclear Fuel Services lease with the NYSERDA expired. The State Departments of Environmental Conservation and Labor, regulators of the disposal area, required Nuclear Fuel Services to continue to maintain the site beyond the lease expiration date until the facility licenses were transferred to NYSERDA. NYSERDA assumed possession of the disposal facility and responsibility for surveillance and maintenance of the site in the spring of 1983.

Monitoring by NYSERDA indicated that, in spite of the trench cap rehabilitation program, water continued to infiltrate into the disposal trenches. Since the last pumping in 1981, the trench water levels in most of the trenches had increased; the most significant increase occurred in Trench 14. A review of trench water level and onsite precipitation data indicated a strong correlation between rainfall and increased water levels in this trench. Trench cover failure was initially suspected, but inspections revealed no identifiable flaws. It was noted, however, that during the spring and summer of 1986, there was an unusual amount of precipitation during frequent severe thunderstorms and, at times, standing water was observed in the field west of Trench 14. Further investigations revealed the presence of a permeable sand and gravel zone within the generally impervious glacial till. This permeable zone was oriented such that it appeared to intersect the trench and came very close to ground surface about 90 ft from the trench. NYSERDA concluded that the sand and gravel zone had the potential to conduct water into the trench, particularly when the ground surface was flooded.

Since it appeared that the water level in the trench was at or slightly below the intersect of the sand and gravel zone, NYSERDA requested and was granted permission to conduct remedial actions. The first phase of remediation was to lower the water level in Trench 14 at least 1 foot below the intersect by transferring the water into two adjacent trenches. This transfer was performed in early February 1987. In mid-February, a subsurface concrete wall was installed immediately west of the trench. This wall was to provide additional protection against water entering the trench, and to create a surface against which the planned extensive excavation work in the sand and gravel zone could be conducted.

In the summer of 1987, NYSERDA completed the remainder of the remedial action project. The effort consisted of removing the entire sand and gravel zone west of the concrete wall, replacing it with compacted clay from a nearby borrow area, grading the affected area for more effective drainage, and establishing a vegetation cover. No contamination was found in the sand and gravel zone.

During the winters of 1990-91 and 1991-92, water levels in several trenches at the site, particularly Trenches 13 and 14, rose substantially. To minimize further rises in trench water levels, a slurry wall approximately 30 ft deep was installed on the west side of Trench 14 during the summer of 1992. In addition, a geo-membrane liner was installed over Trenches 13 and 14 to beyond the slurry wall. Thus far, these modifications have prevented any significant rise in trench water levels.

A test project is being carried out on Trench 9. Fiberglass panels are being used to enhance rainwater runoff from the trench cover and rows of juniper evergreens have been planted to absorb available moisture in the trench cap. Several years of monitoring data will be needed to evaluate the effectiveness of this cap modification.

To provide storage capacity for leachate that may need to be pumped from the trenches, three storage tanks with a capacity of 51,200 gal were installed at the site in 1991. A leachate treatment system has been designed to remove contaminants from the leachate. Construction of the treatment system has been delayed as a result of the success of the corrective measures implemented for Trenches 13 and 14.

Facility Status

Between 1983 and 1986, NYSERDA and the DOE sponsored a project to evaluate options for long-term management of the shutdown commercial LLW disposal facility. The objective was to place the facility in a condition that would eventually require only passive custodial care and monitoring to protect the public health and safety and the environment. Of the seven trench stabilization methods considered, the natural stabilization alternative was selected. Natural stabilization would allow the trenches to settle and stabilize naturally for however long was necessary, perhaps 25 to 50 years. Once the site stabilized, a structural engineered cap would be installed. This plan essentially assumed the continuation of the interim site management program pending site stabilization.

However, NYSERDA has since decided to close the entire Nuclear Service Center when the West Valley Demonstration Project is completed, and has entered into a joint agreement with the Department of Energy to prepare an Environmental Impact Statement (EIS) for completion of the West Valley Demonstration Project and closure of the Center.

Currently, a draft EIS is scheduled to be completed in June 1994. In addition, a Resource Conservation and Recovery Act (RCRA) Facility Investigation is being completed for both the commercial LLW disposal facility and a small separate waste area east of the Nuclear Service Center. Field work for the RCRA Facility Investigation, including sampling of air, soil, surface water, and groundwater, has been completed, and a draft report is scheduled to be submitted to the EPA and the State Department of Environmental Conservation in May 1994.

The West Valley commercial disposal site continues to be maintained in a shutdown status, with the necessary monitoring being conducted by NYSERDA.

Richland, Washington

The Richland commercial LLW disposal site is located on the central plateau of the Hanford Reservation, about 23 miles northwest of Richland, Washington, in the southeastern part of the State. The site consists of 100 acres of land leased by US Ecology, Inc., from a 1,000-acre tract on the Hanford Nuclear Reservation that is leased by the State of Washington from DOE.

Site Description

The Hanford Reservation is located in the Pasco Basin on the semiarid alluvial plain of the Columbia River. The disposal site is situated on glacier-fed river sediments of the ancestral Columbia River that consist of sand, silt, and gravel in various combinations (Figure 8). These deposits are up to about 200 ft deep and overlay the Reingold Formation, which is a layer of sedimentary material up to 1,200 ft thick. Below this formation, the bedrock consists of Yakima Basalt. The land is generally flat with intermittent dunes, except where grading has occurred. The surface dunes consist of fine silt and sand and are subject to migration in areas where the fragile vegetative cover has been destroyed. The depth of the water table beneath the disposal site is about 245 ft, with the bottom of this unconfined aquifer being coincidental with the lowest layers of the Reingold Formation.

The Columbia River flows through the reservation about 6 miles from the commercial LLW disposal site. There are no surface-water bodies on or near the disposal site. Two intermittent streams and a small natural pond are located on the surrounding reservation.

The Pasco Basin is characterized by a semiarid climate, with an average annual precipitation of about 6.3 in. and an annual potential evaporation rate of 55 in.

The Richland commercial LLW disposal site is unique among comparable sites in that it is the only one located on Federal land. The Hanford Reservation includes a number of DOE nuclear research facilities, including reactors, chemical processing plants, laboratories, and supporting facilities. The commercial LLW disposal site is essentially bounded on the east and west sides by two DOE radioactive waste disposal areas that have been used for the disposal of waste since 1944 and are still in active use. The proximity of the commercial LLW disposal site to the DOE disposal areas complicates the ability to distinguish with environmental monitoring potential releases from the LLW site with potential releases from the DOE sites.

The site currently consists of 18 land disposal trenches that vary dimensionally from 300 to 1,000 ft long, 25 to 150 ft wide, and 20 to 45 ft deep (Figure 9). The site also hosts four 30-ft-deep caissons located between Trenches 3 and 4 and three underground steel tanks ranging in size from 1,000 to 20,000 gal (originally there were five tanks; two were removed in the mid-1980s and the remaining three tanks are no longer in use).

Operating History

The disposal site was licensed and opened as a commercial venture in September 1965 and, except for a brief period in 1979, has operated since that time. The first licensed operator of the site was California Nuclear, Inc. In March 1968, the assets of the company were transferred to the

R94 0613

Figure 8. Richland, Washington, disposal site geology.

R94 0543

Figure 9. Richland, Washington, disposal facility map.

Nuclear Engineering Company (NECO), which in 1981 changed its name to US Ecology, Inc.

Washington has been an Agreement State with the NRC since December 1966. Since that time, the State has assumed responsibility for licensing the possession and disposal of source and by-product material, while the NRC retains responsibility for licensing the possession and disposal of special nuclear material exceeding certain limits.

LLW is disposed of primarily by shallow-land burial. The disposal trenches are opened, as needed, and used in an alternating sequence to allow room for the stockpiling of excavated soil and to facilitate trench access. The waste containers are placed in the trench, with a minimum distance of 8 ft left between the top of the waste and the original ground surface. The trench is backfilled with the previously excavated soil. After the trench is filled to the original level, a soil cover is formed into a mound which is at least 5 ft thick along the trench centerline and 3 ft thick near the trench edge. A 6-in. layer of gravel and cobble is then placed on the mound to protect the cover soil against wind erosion and burrowing animal intrusion. The boundaries of the disposal trenches are surveyed and referenced to a concrete post benchmark, which is, in turn, keyed to the site records.

Disposal practices other than the conventional method of disposal in shallow trenches have been used at the Richland facility, including the use of caissons and resin tanks. The caissons are used for the disposal of waste with high surface radiation readings. The caissons consist of four wells, 30 ft deep and lined with steel pipe, which are closed off at both ends with concrete.

Five underground steel tanks, ranging in size from 1,000 to 20,000 gal, were installed in the late 1960s for evaporating and solidifying liquid resin wastes. Their use was discontinued in the early 1970s. The tanks and associated wastes were left in place with little attention until early 1985, when leaks in the tanks and contamination of adjacent soils were discovered. US Ecology, Inc. removed the liquid waste from the tanks and subsequently removed and disposed of two of the five tanks. The remaining three tanks were filled with concrete. US Ecology then placed plastic over the tank area to prevent the contaminated soil from becoming airborne.

During the period between the beginning of waste disposal operations in 1965 and the end of 1993, over 12.5 million ft³ of waste, containing about 34 million curies of by-product material, were disposed at the Richland site (Table 1). In addition, over 13.4 million lb of source material and about 351 lb of special nuclear material were disposed of in that period.

Except for the underground tanks, the Richland LLW disposal facility has experienced no problems related to site operations or waste containment. However, as with the Barnwell and Beatty sites, routine inspections of incoming waste in 1979 led to the discovery of violations of transportation and packaging regulations. Consequently, the disposal site was shut down by the Governor of Washington during October and November of 1979 while problems with incoming waste shipments were resolved. The site was reopened only after assurance was given by the Federal Government that action would be taken to enforce shipper compliance with transportation regulations, and after a compliance certification plan was adopted by the governors of the three States with operating commercial disposal facilities.

Despite these actions, there was continuing public concern over the safety aspects of waste transportation. There was also a growing opinion that the State of Washington should not be a repository for LLW generated in other regions of the country. This culminated in the 1980s in a significant referendum decision by the voters of the State of Washington to close the site to all nonmedical and out-of-State waste shipments after July 1, 1983. However, in response to court challenges, the referendum was declared unconstitutional. This ruling was upheld in the appellate court.

Recently, the Washington Department of Health initiated a LLW generator inspection program that includes State inspections at generator facilities to further ensure compliance with Richland site waste acceptance criteria. This program has been successful thus far, and is expected to further minimize generator non-compliance with waste form, packaging, and transportation requirements.

Facility Status

Washington became a member of the Northwest Compact Region in 1985. As one of the three sited States, Washington was obligated to allow the Richland facility to dispose of wastes generated outside the compact through 1992, as long as the States in which the generators were located continued to meet the milestone prescribed in the LLRWPA of 1985. The LLRWPA of 1985, however, limited the amount of waste the Richland facility was required to accept to 9.8 million ft³ during the seven year period of 1986 to 1992 (based on an average annual volume of 1.4 million ft³ of LLW). In 1993, less than 200,000 ft³ of LLW was disposed in the Richland facility.

Site characteristics, such as the depth to the water table, climatic conditions, and a soil media with high absorptive capacity, together with engineered barriers such as the deep layer of soil placed over the waste, have resulted in favorable performance conditions for LLW disposal at the Richland facility. Environmental monitoring programs are conducted by the DOE, the State of Washington, and US Ecology, Inc. to evaluate levels of radioactivity along potential exposure pathways. The program includes analysis of groundwater in onsite wells, offsite surface water, air, soil, and vegetation. To date, the monitoring program has confirmed that the waste is contained within the disposal trenches and that no migration has occurred.

In 1992, an agreement was reached between the Northwest and Rocky Mountain Compact Regions that allows for disposal of LLW from both Compact Regions at the Richland facility. Disposal costs in 1994 are \$50.48/ft³ with an additional \$10 to \$15/ft³ of fees and riders including \$1.75/ft³ fee for primary care and maintenance. Currently, there is approximately \$18 million set aside in a closure fund for eventual closure of the facility.

The Future

The lease for the Richland site does not expire until the year 2063. Current plans call for a total of 31 trenches at the site with the yearly projected waste volume of 100,000 to 120,000 ft³/yr. The site has a remaining capacity of 43 million ft³ of waste.

The Washington State Department of Ecology has prepared a two-phase report on the eventual closure and perpetual care and maintenance of the Richland disposal facility. The report recommends the use of a multiple-layer cover consisting, from bottom to top, of a cover foundation, a hydraulic barrier, a biotic barrier, a capillary barrier, a gravel-top dressing, and a vegetative surface layer as the closure design. The report also recommends that inspection and monitoring activities be conducted quarterly during the first 25 years of the perpetual care and maintenance period, semi-annually for the second 25 years, and annually through the duration of the institutional control period.

Sheffield, Illinois

In October 1966, the Illinois Department of Public Health signed a lease with California Nuclear, Inc. permitting the establishment of the Sheffield disposal site. The Sheffield LLW disposal site is located about 5 miles southwest of Sheffield, Illinois. Sheffield is about 140 miles west-southwest of Chicago, and about 45 miles east-southeast of Moline. The disposal site originally consisted of 20 acres surrounded by a 170-acre buffer zone next to two hazardous waste disposal areas. The hazardous waste disposal areas are located to the north and northwest of the site. The Sheffield disposal site, opened in 1968, was first operated by California Nuclear, Inc., and later by the Nuclear Engineering Company Inc. (NECO), which is now US Ecology, Inc. Disposal operations ceased in 1978 when the site operator experienced lengthy delays during the license renewal process.

Site Description

The Sheffield LLW disposal site is located on rolling glaciated terrain. The ground in which the disposal trenches were placed consists of wind-blown silt, pebbly clay, water-deposited sand and gravel, lake deposits of silt and clay, and silty, sandy stream sediments (Figure 10). The site is underlain by both shallow and deep aquifers. The bedrock underneath the site is approximately 450 ft thick and provides a relatively impermeable barrier between the two aquifers. A pebbly sand unit extending across the middle of the site, and continuing offsite to the northeast, lies under approximately two-thirds of the site and forms the most permeable unit at the site. This pebbly sand unit serves as an underground drain, carrying the bulk of the groundwater from the site.

The site is in the headwater tributaries of Lawson Creek, which is 1 mile east of the site at its nearest point. Three small intermittent streams drain the Sheffield site. Two streams drain the southern portion of the site, and the third drains the northern portion of the site. An abandoned strip mine pit, now filled with water and called Trout Lake, is located 800 ft northeast of the disposal site. The climate is humid with a mean annual precipitation of about 35 in.. This exceeds evapotranspiration by about 10%.

The waste is buried in 21 separate trenches (Figure 11). A typical trench is 500 ft long, 50 to 60 ft wide, and 20 to 25 ft deep. A minimum of 10 ft separates the trenches at the surface.

Operating History

R94 0614

Figure 10. Sheffield, Illinois, disposal site geology.

This map is an artist's rendering from inexact input and is therefore not accurate as to measurements and distance.

R94 0609

Figure 11. Sheffield, Illinois, disposal facility map.

Since the Sheffield site was established, regulatory responsibilities for site activities have been shared by the State of Illinois and the U.S. Atomic Energy Commission, now the NRC. The NRC regulated the possession and disposal of by-product, source, and special nuclear material at the site. The Illinois Department of Public Health owns the 20 acres of land used for LLW disposal and regulates possession and disposal of naturally occurring and accelerator-produced materials. The original California Nuclear, Inc. licenses were transferred to Nuclear Engineering Company, Inc. (NECO), now US Ecology, Inc., in March 1968. US Ecology, Inc. remains the licensee for the site.

The site was used for disposal of LLW from August 1967 through April 1978. During that time, over 3 million ft³ of waste material containing about 60,000 curies of by-product material, 126 lb of special nuclear material, and about 1 million lb of source material, were buried within the original 20-acre tract (Table 1).

Basis for Facility Closure

The growth of the nuclear power industry in the early 1970s rapidly increased the demand for LLW disposal space. The annual volume of waste received at Sheffield increased from about 9,000 ft³ in 1970, to about 57,000 ft³ in 1977, the year before the site was closed. In 1975, the Nuclear Engineering Company, Inc. requested the NRC issue a modification to its license that would permit compacted-fill trenches and, thereby, increase the capacity and lifetime of the original 20-acre tract. The NRC requested that NECO supply additional information and also prepare an environmental report. In December 1975, the NRC authorized construction of the new trenches but withheld approval to bury waste in these trenches until NECO submitted the requested information. About one year later, NECO submitted the environmental report and also requested expansion of the site as part of its application for license renewal. In August 1977, while the renewal-and-expansion application was being reviewed by the NRC, NECO requested that its license be amended to permit the construction of a new trench, Trench 15, in the originally licensed 20-acre tract.

The original description of the site geology was based on information gained from a total of eight borings. Based on the information obtained from these borings both the applicant and the United States Geological Survey (USGS) concluded that the site was suitable for disposal of LLW. These early investigations also led to some conclusions on groundwater movement at the site. Based on the available information, the groundwater velocity was estimated to be between 3.5 and 7.0 ft per year. On review, the USGS increased this estimate to between 10 and 20 ft per year, stating that the velocity was dependent largely on the assumed geologic conditions at the site. In 1976, the USGS initiated a five-year study to further examine the site-specific geology and hydrogeology.

In December 1977, tritium was found in samples taken from monitoring wells constructed by the USGS in the southeast corner of the site. It appeared that the tritium was migrating from Trench 11 and that the rate of groundwater movement from this trench significantly exceeded the original estimates. To further explore the site hydrogeology, the USGS performed a horizontal boring in the southeast corner of the site between December 1978 and March 1979. The information obtained from this boring indicated that the presence of permeable sand and other coarse-grained deposits were far more extensive than discovered by the original site investigation.

In March 1978, the NRC ruled that Trench 15 could not be used for waste disposal. With the expansion application pending and no space in other trenches, the NRC ruling on Trench 15 led to a de facto closure of the site. In April 1978, NECO withdrew its application for Trench 15 and ceased disposal of LLW.

Postclosure History

In the late 1970s and early 1980s, the USGS installed additional monitoring wells at the north and east boundaries of the site because the general hydrogeologic studies indicated groundwater movement to this area. In November 1981, tritium was detected in one of these wells. This was significant because it marked the first time that tritium had been detected beyond the original site boundary. Additional wells installed to the northeast of the site confirmed tritium movement in shallow groundwater through narrow channel fill deposits to the northeast to Trout Lake. The pathway for this radionuclide migration was believed to be intrusion of water into the disposal trenches, leaching of contamination from the waste, followed by leachate movement offsite via the permeable sand deposits.

The permeable sand deposits empty into Trout Lake via three springs. These springs are located at the end of the northeast pathway and were found to contain tritium in 1982. Based on studies by the Illinois Department of Nuclear Safety, tritium concentrations in the wells and springs along the pathway appear to vary cyclically with precipitation. Tritium concentrations in on-site groundwater monitoring wells have ranged up to 1,300,000 pCi/l, but have been decreasing to under 500,000 pCi/l as of October 1992 due to the installation of a low permeability cap over the trenches in late 1989. Concentrations of tritium in groundwater beyond the disposal site remain below the Federal Primary Drinking Water Standard for tritium of 20,000 pCi/l. Tritium concentrations in the public and private drinking water supplies remain well below this standard.

Since the initiating event for the radionuclide migration was water intrusion, water management became an integral part of site maintenance. Trench covers were graded to enhance precipitation runoff into drainage ditches, and water that did infiltrate the trenches was collected in sumps located in each trench and removed.

Facility Status

In March 1978, US Ecology, Inc. attempted to terminate its license and lease with the State of Illinois. The State responded by filing suit against the company, saying that the company could not sever its contractual relationship with the State. The State sought a \$97 million judgment against the company in a dispute over who was responsible for maintenance of the site. In May 1988, US Ecology, Inc. and the State of Illinois entered a settlement agreement that provided a plan for the closure, care, and maintenance of the LLW disposal site. The agreement was submitted to the Illinois Circuit Court of Bureau County and the lawsuit was dismissed with prejudice. Under the terms of the Agreed Order, US Ecology, Inc.: (a) established a long-term maintenance fund of \$2.5 million, (b) established a \$1.65 million escrow account conditioned on completing the terms of the settlement agreement, (c) completed specified physical improvements to the site including placement of a clay cap, (d) started a chemical and radiological monitoring program, and (e) must maintain the site until June 1998, after which site, buildings, and equipment are to be turned over to the State.

In September 1989, US Ecology, Inc. completed dynamic compaction of the trenches and the construction of a new clay cap over the entire site, an improvement specified in the settlement agreement. The cap, designed to reduce water infiltration, consists of 4.5 ft of compacted clay, covered with six in. of vegetated topsoil. US Ecology has implemented a revised environmental monitoring program that includes testing ground and surface water, soil, fish, and vegetation for radioactive and hazardous chemical contamination. New groundwater monitoring wells were also installed at the site.

US Ecology, Inc. and the State are in the middle of a 10-year period of monitoring and maintenance. At the end of this period in 1998 and upon completion of all settlement terms, the State of Illinois will assume ownership of the site and US Ecology, Inc. will be released from further responsibilities.

Barnwell, South Carolina

The Barnwell LLW disposal facility was originally licensed for aboveground storage of LLW in November 1969. The license was amended in April 1971 to permit Chem-Nuclear Systems, Inc. (CNSI), the site operator, to bury LLW, and waste disposal was then initiated. Since then, the Barnwell site has operated continuously. The site is owned by the State of South Carolina and is leased to CNSI by the State Budget and Control Board. The Barnwell site is located near the eastern boundary of the DOE's Savannah River Plant in the southwestern part of South Carolina. The disposal site consists of 300 acres of land located about 5 miles west of the town of Barnwell, South Carolina, and on the edge of the small community of Snelling.

Site Description

The site is located on part of the Coastal Plain geologic province, which is characterized by flat, largely unconsolidated sediment layers (Figure 12). Onsite soil consists of a layer of topsoil containing sand, clay, and organic material, overlying a layer of fine sands and silty sands (2-7 ft thick), followed by the sandy clay and dense clays (14-30 ft thick) of the Hawthorne Formation. A regional groundwater table lies within the Hawthorne Formation at depths that range from 30 to 60 ft. The principal source of potable water in the area is from the deeper Middendorf Formation at depths in excess of 350 ft.

The nearest surface water to the site is Lower Three Runs Creek, which is about 3 miles away. This creek, a tributary of the Savannah River, drains the major portion of the site and flows into the river about 70 miles downstream. However, because of the gentle slope of the topography and the absorptive nature of the sand cover, surface water runoff occurs only after unusually heavy rainfall.

The climate at the site is mild and humid, with a mean annual precipitation of 47 in. (ranging from 29 to 73 in.). Regionally, about 15 in. of the annual average rainfall infiltrates to the water table. The shallow monitoring wells at the site are screened in the Hawthorne Formation at depths ranging from 35 to 70 ft. The water table aquifer flows at a rate of approximately 7 ft per year. Water supply wells in the Barnwell area are screened in the deeper McBean and Middendorf aquifers.

R94 0612

Figure 12. Barnwell, South Carolina, disposal site geology.

The site currently consists of 73 standard trenches and seven slit trenches (Figure 13). The standard trenches vary dimensionally, from the initial four trenches that are each 200 ft long by 50 ft wide by 15 ft deep, to the current typical unit that is 1,000 ft long by 100 ft wide by 21 ft deep. The slit trenches, which are used to dispose of Class C waste, are 4 ft wide by 500 ft long and about 22 ft deep.

Operating History

South Carolina became an NRC Agreement State in 1969. As an Agreement State, South Carolina licenses the operation of the LLW disposal facility, through the State Department of Health and Environmental Control, under authority delegated by the NRC. The operating license covers the possession and disposal of source and by-product material, while a separate NRC license covers the possession and disposal of special nuclear material.

LLW is disposed of primarily by shallow-land disposal. The disposal trenches are constructed to facilitate the collection and removal of leachate, with a floor sloping to one side, where a French drain runs the length of the trench and is sloped about 0.3%. Water collection sumps are placed at 500-ft intervals along the French drain, and standpipes, for removal of leachate, are located in the sumps and at intervals along the trench. A layer of sand (2-3 ft thick) is placed on the bottom of each trench to provide an even foundation for waste packages and to ensure that any water entering the trench will drain from the bottom layers of waste and into the French drain for collection. Layers of sand in the trench walls are replaced with compacted clay to reduce lateral infiltration of moisture into the trenches from the surrounding soil.

Figure 13. Barnwell, South Carolina, disposal facility map.

Waste is typically placed in the trench, starting at the high end of the trench floor, by stacking boxes and components and then filling the intervening spaces with drums and small packages. Upon completion of waste emplacement, trenches are backfilled with sand to fill remaining voids between packages and provide drainage paths away from the waste for any rainwater infiltrate. A layer of soil with a minimum thickness of 3 ft is then placed over the trench, followed by a layer of compacted clay at least 2-ft thick. Topsoil, 6–18 in. deep, is applied and a cover crop planted. The completed trench is located with permanent granite markers at the ends and at the four trench corners, which are keyed to the site records.

Waste with a high surface radiation level is disposed of in slit trenches. The deep, narrow trench aids in minimizing exposure to workers during offloading operations. The trenches are excavated in 125-ft segments to prevent cave-ins. Gravel is added to the trench floor in 1–3 ft depths to provide rapid water drainage. Once waste is placed in the trench, clay is backfilled over the package to reduce radiation emission from the area. As on the standard trenches, a clay cap and concrete intruder barriers are installed later.

From the beginning of disposal operations in 1971 through 1989, over 24.8 million ft³ of waste containing about 7.1 million curies of by-product material were disposed at the site (Table 1). In addition, over 33 million lb of source material and 6,739 lb of special nuclear material were disposed of in that period.

The Barnwell LLW disposal facility has not had significant problems specifically related to either site operations or to onsite waste management. However, as with the Richland and Beatty sites, the Barnwell facility has discovered waste packaging and transportation violations. Unlike the Beatty and Richland facilities, the violations were not severe enough to close the Barnwell facility. When the volume of waste received at the site increased substantially, and after closure of three of the other sites, the Governor of South Carolina instituted a program in 1979 which began a two-year phase-down of the volume of waste accepted at the Barnwell site to 1.2 million ft³/year (almost a 50% reduction). In 1979, the developing problems led to unified actions to tighten generator and transporter compliance procedures, as well as actions to upgrade waste-acceptance standards at the three sites. This was accomplished by imposing new license provisions and adopting administrative constraints. CNSI performs random inspections of waste to verify compliance with waste acceptance criteria.

Facility Status

South Carolina became a member of the Southeast Compact Region in 1985. As one of the two States with active disposal sites, South Carolina allowed the Barnwell facility to dispose of wastes generated outside the Compact Region through June 1994, as long as the States in which the generators are located continued to meet prescribed milestones of the LLRWPA of 1985. The LLRWPA of 1985, however, limited the amount of waste Barnwell was required to accept to 8.4 million ft³ in the 7-year period of 1986 to 1992 (based on an average annual volume of 1.2 million ft³ of LLW). Through December 1995, the Barnwell facility will accept wastes generated only within the Southeast Compact.

Partly as a result of the limits on allowable volume and the additional operating constraints imposed, unit disposal costs have increased considerably in recent years, the 1994 basic rate being

\$59/ft³. There are additional incremental costs for decommissioning the site upon closure and for providing a perpetual care fund for the site. These combined charges were approximately \$12.60/ft³ in 1994 and are transferred to the State. This fund contained over \$56 million in 1994. Additional charges include a \$6/ft³ radioactive waste tax and a \$220/ft³ surcharge on non-Southeast Compact Region waste. Barnwell County also imposes a 2.4% tax on all disposal fees. Therefore, total charges are approximately \$78/ft³ for Southeast Compact Region waste and about \$300/ft³ for non-Southeast Compact Region waste.

The environment surrounding the facility is closely monitored. The Barnwell site operator, CNSI, monitors onsite and offsite wells quarterly for signs of radioactive contamination. Tritium concentrations in the shallow monitoring wells at the site (approximately 1,500 pCi/l) are slightly elevated above average tritium concentrations in Barnwell County (about 540 pCi/l). These concentrations are well below the Federal Primary Drinking Water Standard for tritium of 20,000 pCi/l. Moreover, water supply wells in the Barnwell area are screened in deeper aquifers such as the McBean and Middendorf Formations which are not expected to be adversely impacted by tritium.

Groundwater monitoring by CNSI detected the migration of radionuclides in the uppermost water-bearing zone (Hawthorne Formation) from the older trenches in 1976. Remedial actions, including recapping the older trenches, have slowed the migration to less than a foot per year. No elevated levels of radionuclides have been detected in the underlying regional aquifer (Middendorf Formation).

In addition to groundwater monitoring, periodic sampling of soil, plants, and animals is conducted and the air is monitored on a continuous basis. The contamination control program is governed by levels specified by the license conditions and is subject to inspection by State personnel. There have been no problems on the site related to excessive surface contamination or to the spread of contamination through waste handling.

The Future

Under terms of the Southeastern Regional Compact, South Carolina will cease to be the regional disposal facility by December 31, 1995. The Southeast Compact Commission has designated North Carolina as the next Host State. Upon closure of the Barnwell facility, the State of South Carolina will oversee the decommissioning and stabilization of the site. The land will be stabilized according to a predeveloped plan drafted by CNSI and approved by the State. The plan will incorporate schedules for closure, estimated costs for passive maintenance of buffers and trench caps, and an environmental monitoring plan. The final draft of the closure plan is currently being reviewed by the State.

After the site is closed, all equipment will either be decontaminated or disposed of, and the area will be graded to drain water away from the trenches and to minimize erosion of the trench covers. A passive site security system will remain in effect, and will require minimum maintenance.

A Decommissioning and Perpetual Care Fund has been established for the long-term maintenance of the site. This fund will be used to provide equipment necessary for environmental monitoring and any maintenance that may be necessary to trenches, security systems, and equipment. Perpetual care and maintenance of the site will be performed by a designated State agency for a period of at least 100 years.

GLOSSARY

Active maintenance	Any significant remedial activity needed during the period of institutional control to maintain a reasonable assurance that the performance objectives of 10 CFR Part 61 are met.
Activity	The rate at which a radioactive material emits radiation.
Adsorption	Adhesion of molecules to the surface of solid bodies with which they are in contact.
Agreement State	A State which has entered into an agreement with the Nuclear Regulatory Commission to license and regulate its own commercial low-level radioactive waste disposal facilities and low-level radioactive waste management activities.
Aquifer	A body of rock that is sufficiently permeable to conduct ground water and to yield economically significant quantities of water to wells and springs.
Aquitard	An underground bed or stratum of impermeable material, that acts as a barrier to water movement.
By-product material	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.
Curie	A unit of radioactivity defined as the amount of radioactive material having an activity of 37 billion disintegrations per second. Millicurie: One-thousandth of a curie. Microcurie: One-millionth of a curie. Nanocurie: One-billionth of a curie.
Decay (radioactive)	The decrease with time of the amount of radioactive material present, as a result of the disintegration process leading to the formation of stable, nonradioactive elements.
Desiccation	The act of removing moisture from an object. Desiccative cracks are cracks in the ground caused by the drying action of the sun.
Dismissed with prejudice	A legal term meaning that once the case is dismissed, the plaintiff is not allowed to bring suit against the defendant on the same charge.
Erosion	The process by which soil and rock materials are carried away by the action of wind or water.
Evapo-transpiration	The total water loss from an area, being the sum of evaporation from the soil and transpiration from vegetation.

French drain	A gravel- or cobble-packed trench designed to collect and carry fluid along its entire length and to support a vertical load.
Glacial drift	Sediments transported in, or deposited by, glaciers.
Groundwater	Subsurface water which is located within a zone of saturation.
Grout	Various materials (such as a mixture of cement and water or chemicals that solidify) used for filling spaces.
Half-Life	The amount of time it takes for any amount of a radioactive substance to decay to one half that amount. See Appendix A.
Host State	A State which has, or is planning to have, a low-level radioactive waste disposal facility.
Hydrology	The study of the water of the earth.
Institutional control	The period of time following closure of the disposal facility during which the site custodial agent maintains control of the facility and monitors its performance. Institutional control is assumed to continue indefinitely, but in technical analysis, control of the site may be assumed to last for only 100 years after facility closure.
Ion-exchange resins	Small resin beads used to remove radioactive ions or dissolved solids from contaminated liquid.
Leachate	A solution obtained by the action of a percolating liquid dissolving the substance through which it moves.
Lithology	The physical character of a rock determined by low-power magnification, e.g., mineral composition, grain size, and structure.
Migration (radionuclide)	The movement of radionuclides through air, soil, or water. See Appendix B.
Passive Custodial Care	Routine care of a closed disposal facility which does not involve active maintenance.
Permeable	Having a texture that permits the movement of liquids or gases.
Plastic	Being able to be molded into any shape and then retain that shape.
Precipitation	Water deposited on the earth in the form of hail, mist, rain, sleet, or snow.

Radionuclide	A radioactive species of an atom having a specific mass, atomic number, and nuclear energy state. Radionuclides are unstable and, therefore, radioactive.
Source material	Uranium, thorium, or a combination of both.
Special nuclear material	Plutonium, uranium-233, uranium-235, and any material artificially enriched by any of the foregoing.
Subsidence	The sinking of a large part of the earth's surface. In the context of this report, subsidence refers to the sinking of a disposal trench's earthen cover caused by the decomposition and settling of the waste.
Surface water	Water contained on the surface of the earth, i.e., rivers and lakes.
Till	Unstratified glacial drift consisting of clay, sand, gravel, and boulders intermingled.
Transuranics	Elements or radionuclides with an atomic number greater than that of uranium (i.e., greater than 92). Transuranic radionuclides normally have substantially longer half-lives than nontransuranic radionuclides, although this is not always the case.

READING LIST

1. Brown, H., *The Low-level radioactive waste Handbook: A User's Guide to the Low-Level Radioactive Waste Policy Amendments Act of 1985*, November 1986. This guide provides a section-by-section discussion of the development of the Low-Level Radioactive Waste Policy Amendments Act of 1985. Write: The National Governor's Association, Hall of the States, 400 North Capitol St., Washington, D.C. 20001-1572.
2. Hurley, P.M., *Living with Nuclear Radiation*, 1982. This document discusses the risks associated with natural and human-made sources of radiation. Write: University of Michigan Press, Box 1104, 839 Greene St., Ann Arbor, MI 48106.
3. League of Women Voters, *The Nuclear Waste Primer: A Handbook for Citizens*, 1993. This document provides an overview of problems associated with nuclear waste and its management. It describes how citizens can be involved in nuclear waste decisionmaking and identifies selected information sources. Write: Nick Lyons Books, 31 West 21 St., New York, NY 10010.
4. Murray, R.L., *Understanding Radioactive Waste*, 1989. This document provides simple and clear information on all aspects of radioactive wastes. Write: Battelle Press, 505 King Avenue, Columbus, OH 43201.
5. National Conference of State Legislatures, *Low-Level Radioactive Waste Management: An Update*, 1994. This document provides an overview of commercial low-level radioactive waste disposal issues in the United States. Write: National Conference of State Legislatures, Office of State Services, 1050 Seventeenth St., Suite 2100, Denver, CO 80265.
6. Office of Technology Assessment, *Partnerships Under Pressure: Managing Commercial Low-Level Radioactive Waste*, November 1989. This document reports the status of State and regional compact progress towards developing low-level radioactive waste disposal facilities. Write: Superintendent of Documents, Government Printing Office, Washington, D.C. 20402-9325.
7. U.S. Department of Energy, "Answers to the Most Frequently Asked Questions About Low-Level Radioactive Waste Disposal in the United States." This pamphlet is a compilation of the most frequently asked questions about the disposal of low-level radioactive waste, and the Department of Energy's responses to these questions. Write: EG&G Idaho, National Low-Level Waste Management Program, P.O. Box 1625, Idaho Falls, ID 83415-2420.
8. U.S. Department of Energy, "Low-Level Waste Management Perspectives." This series of fact sheets provides a basic overview of radioactivity, low-level radioactive waste, and low-level radioactive waste management. Write: EG&G Idaho, National Low-Level Waste Management Program, P.O. Box 1625, Idaho Falls, ID 83415-2420.
9. U.S. Department of Energy, *1992 Annual Report on Low-Level Radioactive Waste Management Progress*. This report describes the activities and progress of the Compact

Regions and unaffiliated States in 1992 in developing new disposal sites for low-level radioactive waste. In addition, the report summarizes information on low-level radioactive waste volumes shipped to the three operating disposal sites in 1992. Write: EG&G Idaho, National Low-Level Waste Management Program, P.O. Box 1625, Idaho Falls, ID 83415-2420.

10. U.S. Geological Survey, *Hydrogeological Factors in the Selection of Shallow Land Burial Sites for the Disposal of Low-Level Radioactive Waste*, 1986. This document provides an overview of the impact of hydrogeology on the siting of a shallow-land low-level radioactive waste disposal site. Write: Open-File Services Section, U.S. Geological Survey, Box 25425, Federal Center, Denver, CO 80225.
11. U.S. Nuclear Regulatory Commission, "Regulating the Disposal of Low-Level Radioactive Waste: A Guide to the Nuclear Regulatory Commission's 10 CFR Part 61," August 1989. This brochure provides: (a) an overview of 10 CFR Part 61 requirements, (b) an overview of the history and background of low-level radioactive waste management, and (c) answers for some common questions about low-level radioactive waste management. Write: Division of Low-level radioactive waste Management and Decommissioning, Mail stop 5 E4, Office of Nuclear Material Safety and Safeguards, Washington, D.C. 20555.

BIBLIOGRAPHY

- A. T. Kearney, Inc., *Closure and Perpetual Care and Maintenance of the Commercial Low-Level Radioactive Waste Disposal Facility on the Hanford Reservation, Phase One Report*, September 1987.
- A. T. Kearney, Inc., *Closure and Perpetual Care and Maintenance of the Commercial Low-Level Radioactive Waste Disposal Facility on the Hanford Reservation, Phase Two Report*, February 1989.
- Anderson, D. B., *Surveillance and Maintenance of the West Valley State Licensed Low-Level Radioactive Waste Disposal Area 1983-1987*, 1988.
- Brown, H., *The Low-level radioactive waste Handbook: A User's Guide to the Low-Level Radioactive Waste Policy Amendments Act of 1985*, November 1986.
- Cahill, J. M., *Hydrology of the Low-Level Radioactive Solid Waste Burial Site and Vicinity Near Barnwell, South Carolina*, U.S. Geological Survey Open-File Report 82-863, 1982.
- Case, M. J. and Otis, M. D., *Guidelines for Radiological Performance Assessment of DOE Low-Level Radioactive Waste Disposal Sites*, July 1988.
- Chem-Nuclear Systems, Inc., *Economic Benefits of Chem-Nuclear's Low-Level Radioactive Waste Disposal Site to South Carolina*, December 1986.
- Dames & Moore, Inc., *Assessment of the Levels, Potential Origins and Transport Routes of the Radioactivity Measured in the Vicinity of the Maxey Flats Low-Level Radioactive Waste Disposal Site*, March 1977.
- Dames & Moore, Inc., *Evaluation of Alternatives for the Future of Facilities at the Western New York Nuclear Service Center, White Plains, New York*, August 1978.
- Dames & Moore, Inc., *Water and Sludge Management Alternatives for the Maxey Flats Low-level radioactive waste Disposal Site*, March 1980.
- Dragonette, K., Blackburn, J., and Cartwright, K., *Interagency Task Force Report on the Proposed Decommissioning of the Sheffield Nuclear Waste Disposal Site*, Nuclear Regulatory Commission Informal Report, September 1979.
- Envirosphere Co., *Environmental Review of the Commercial Low-Level Radioactive Waste Disposal Facility Within the U.S. Department of Energy's Hanford Site*, August 1985.
- Jacobs, R. G., Epler, J. S., and Rose, R. R., *Identification of Technical Problems Encountered in the Shallow Land Burial of Low-Level Radioactive Wastes*, ORNL/SUB-80-13619/1, March 1980.

- Haight, C. P., and Mills, H. D., "Remedial Action - Maxey Flats Low-level radioactive waste Disposal Site, CERCLA Action," *Proceedings of the Ninth Annual DOE Low-level radioactive waste Management Conference: Session 5, Site Closure and Stabilization*, August 1987.
- Hobson, N., *Deserts as Dumps*, "Chapter 9: Disposal of Low-Level Radioactive Waste and Hazardous Chemical Waste at US Ecology's Beatty Nevada Disposal Facility," (Anticipated publication spring 1990).
- Illinois Department of Nuclear Safety, Environmental Monitoring Report: "Sheffield Low-Level Radioactive Waste Disposal Site, 1967-1988," March 1989.
- Lyverse, M. A., "Tritium Migration at the Low-Level Radioactive Waste Disposal Site at Maxey Flats near Morehead, Kentucky," Proceedings of the Seventh Annual Participants' Information Meeting DOE Low-level radioactive waste Management Program, February 1986.
- New York State Energy Research and Development Authority, Executive Summary of the *Site Stabilization Study for the LLRW Disposal Area at West Valley, New York*, December 1986.
- Office of Technology Assessment, *Partnerships Under Pressure: Managing Commercial Low-Level Radioactive Waste*, November 1989.
- Report to the Chairman, Subcommittee on Energy and Power, Committee on Interstate and Foreign Commerce, House of Representatives of the U.S., Comptroller General, EMD-80-69, "Status of Efforts to Clean Up the Shut Down Western New York Nuclear Service Center," June 6, 1980.
- South Carolina, Chapter 48 of the Code of Laws of South Carolina, 1976.
- South Carolina Department of Health and Environmental Control Regulation No. 61-83, "Transportation of Radioactive Waste into or within South Carolina," May 22, 1981.
- South Carolina Department of Health and Environmental Control, *Low-Level Radioactive Waste Disposal in South Carolina*, 198x.
- State of Illinois v. Teledyne, Inc., and US Ecology, Inc., March 25, 1978.
- State of Nevada License No. 13-11-0043-02, June 29, 1977.
- State of South Carolina, Radioactive Materials License, License No. 097 (amended), Licensee Chem-Nuclear Systems, Inc.
- State of Washington, Radioactive Materials License, License No. WN-1019-2 (amended), Licensee US Ecology, Inc.
- State of Washington Executive Order EO 79-09, Relating to the Transport of Commercial Low-Level Radioactive Waste, November 19, 1979.

- U.S. Department of Energy, *1992 Annual Report on Low-Level Radioactive Waste Management Progress*, November 1993.
- U.S. Department of Energy, Western New York Nuclear Service Center Study, Companion and Summary Reports, November 1978.
- U.S. Department of Energy, *Spent Fuel and Radioactive Waste Inventories, Protections, and Characteristics*, December 1985.
- U.S. Ecology, Inc., Comprehensive Facility Utilization Plan; US Ecology LLRW Facility, Richland, WA, November 1986.
- U.S. Ecology, Inc., *Site Stabilization and Closure Plan for Low-Level Radioactive Waste Management Facility US Ecology, Inc., Beatty, Nevada*, December 1988.
- U.S. Environmental Protection Agency, *Storage of Low-Level Radioactive Wastes in the Ground - Appendix on the Maxey Flats, Kentucky, Radioactive Waste Storage Site - Current Knowledge and Data Needs for a Quantitative Hydrogeologic Evaluation*, 1974.
- U.S. Geological Survey, *Groundwater Hydrology and Subsurface Migration of Radionuclides at a Commercial Radioactive-Waste Burial Site, West Valley, Cattaraugus County, New York*, 1986.
- U.S. Nuclear Regulatory Commission, *Review of the Federal/State Program for Regulation of Commercial Low-Level Radioactive Waste Burial Grounds*, NRC Task Force Report, March 1977.
- U.S. Nuclear Regulatory Commission, *Low-Level Radioactive Waste Burial Criteria*, 1E Information Notice No. 80-24, May 1980.
- U.S. Nuclear Regulatory Commission, *Final Environmental Impact Statement on 10 CFR Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste"*, November 1982.
- U.S. Nuclear Regulatory Commission, *Draft Environmental Impact Statement on 10 CFR Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste"*, September 1981.
- U.S. Nuclear Regulatory Commission, *Background Information for the Development of a Low-level Radioactive Waste Performance Assessment Methodology Identification of Potential Pathways*, December 1989.
- Waste Management Group, Inc., *Directions in Low-Level Radioactive Waste Management "Low-Level Radioactive Waste Disposal: Commercial Facilities No Longer Operating"*, October 1982.
- Waste Management Group, Inc., *Directions in Low-Level Radioactive Waste Management "Low-Level Radioactive Waste Disposal: Currently Operating Commercial Facilities"*, September 1983.

Appendix A

Radiation Basics

Appendix A

Radiation Basics

Everything in the world is made of atoms. In most of these atoms, the number of protons and neutrons in the nucleus are in equilibrium, and the atoms are therefore stable or nonradioactive. However, a few kinds of atoms found in nature are unstable or radioactive (for example, uranium, radium, and thorium). The invention of high-energy accelerators and nuclear reactors has allowed the creation of other radioactive atoms, which are unstable counterparts to naturally stable elements. The unstable atoms emit particles (protons, neutrons, or electrons) and/or energy until they reach a stable, nonradioactive state. These emissions from the unstable atom constitute radiation.

Types of Radiation

The kind of radiation emitted, its amount of energy, and the period of time it takes to again become stable differs for each radioactive atom. The three basic types of radiation are alpha, beta, and gamma radiation. A radioactive substance may emit one of these kinds of radiation or a combination of the three.

Alpha radiation consists of particles, each of which is a cluster of two protons and two neutrons ejected from an unstable nucleus. Alpha radiation loses its energy very quickly when passing through matter (Figure A-1). As a result, most alpha radiation travels only a few inches in air and can be stopped by a sheet of paper or the outer layer of human skin. Alpha radiation can be very damaging to body organs, especially lungs, if the alpha source atoms are inhaled as fine particles.

Beta radiation also consists of particles. In this case electrons, about 1/7,400 the size of alpha particles, are emitted. Beta particles travel farther in air than alpha particles (as far as 12 to 15 feet) and can penetrate several layers of human skin. Because beta particles can penetrate the skin, the human body can be damaged by being near a source of beta radiation for a long period of time or by ingesting a source of beta radiation. Beta radiation can be reduced or stopped by sheets of aluminum, glass, plastic, or wood about an inch thick.

Gamma radiation does not consist of particles, but of waves of energy. It is like light waves or radio waves, but it contains much more energy. Gamma radiation can travel great distances and easily penetrate matter. It can pass completely through the human body, damaging cells enroute, or be absorbed by tissue and bone. Three feet of concrete or two inches of lead are required to stop 90% of typical gamma radiation.

Radioactive Decay

Through the process of radioactive decay, all radioactive elements eventually reach a stable state and stop emitting radiation. The amount of time these elements take to reach stability varies greatly among the different atoms and is measured in "half-lives." A half-life is the time in

Figure A-1. Radiation penetration.

which half the atoms of a particular radioactive substance decay to another nuclide. All radioactive elements have precise and predictable half-lives, ranging from a fraction of a second to more than a billion years (Table A-1).

What this means for low-level radioactive waste disposal is that the risk from a low-level radioactive waste disposal facility naturally decreases with time because the amount of radioactivity remaining at the facility decreases exponentially over time (Figure A-2). For example, the West Valley, New York disposal facility had received approximately 106,000 curies of tritium (H-3) before operations ceased in 1975. Since tritium has a half-life of 12.3 years, by 1988 half of the tritium had decayed leaving only 53,000 curies. By 2001, half of the remaining tritium will have decayed, leaving only 26,500 curies. It is through this process of radioactive decay that disposal sites become less and less hazardous and eventually reach a state when the consequences of intrusion are negligible.

Table A-1. Half-lives for representative radionuclides in commercially generated low-level radioactive waste.

Radionuclide	Symbol	Half-Life
Americium-241	Am-241	432.2 years
Antimony-125	Sb-125	2.77 years
Barium-137m	Ba-137m	2.55 minutes
Carbon-14	C-14	5730 years
Cerium-144	Ce-144	284.3 days
Cesium-134	Cs-134	2.06 years
Cesium-137	Cs-137	30.17 years
Chromium-51	Cr-51	27.7 days
Cobalt-58	Co-58	70.8 days
Cobalt-60	Co-60	5.27 years
Europium-152	Eu-152	13.6 years
Europium-154	Eu-154	8.8 years
Europium-155	Eu-155	4.96 years
Hydrogen-3	H-3	12.3 years
Iron-59	Fe-59	44.63 days
Manganese-54	Mn-54	312.7 days
Niobium-95	Nb-95	35.06 days
Promethium-147	Pm-147	2.62 years
Praseodymium-144	Pr-144	17.28 minutes
Plutonium-238	Pu-238	87.75 years
Plutonium-239	Pu-239	24,130 years
Radium-226	Ra-226	1600 years
Rhodium-106	Rh-106	299 seconds
Ruthenium-106	Ru-106	368.2 days
Samarium-151	Sm-151	90 years
Strontium-90	Sr-90	28.6 years
Technetium-99	Tc-99	213,000 years
Tellurium-125m	Te-125m	58 days
Thorium-232	Th-232	14 billion years
Uranium-235	U-235	704 million years
Uranium-238	U-238	45 million years - 4.5 billion
Yttrium-90	Y-90	61 hours
Zinc-65	Zn-65	244 days
Zirconium-95	Zr-95	64 days

From U.S. Department of Energy, Integrated Data Base for 1993: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics, September 1993.

NOTE TO TABLE A-1: Low-level radioactive waste typically contains both short-lived and long-lived radionuclides. Concentrations of short-lived radionuclides permitted in the waste are higher than concentrations of long-lived radionuclides, because the short-lived nuclides will significantly decay during the 100 years of assumed institutional

control. Low-level radioactive waste that exceeds certain concentrations of long-lived radionuclides is the responsibility of the Federal Government and will not be disposed of in commercially operated disposal sites.

Figure A-2. Natural decay curve of radionuclides.

Radiation Exposure

Most of us are familiar with the Geiger counter, one type of instrument used to measure radiation. Similar instruments can measure amounts and types of radioactivity in the air, soil, water, or on the surface of objects. Each radioactive atom has its own signature, which consists of the types of radiation it emits, the specific energy levels of the radiation, and its precise rate of decay. By measuring these three things, scientists can identify a radioactive atom and know how much of it there is, even if the amount is very small.

Quantities of radiation are measured and expressed in several ways. Most useful for this discussion is the unit called a "rem," because it takes into account both the energy carried by the

radiation and the way that energy is absorbed in biological tissue. A rem (roentgen equivalent man) is a unit used in radiation protection to measure the amount of damage to human tissue from a dose of radiation. Because whole rem exposures are rare, the unit most often used is the "millirem," or 1/1,000 rem. One hundred millirem equals 1/10 rem; 500 millirem equals 1/2 rem; and so on. Another unit that is related to the rem, and which is sometimes referenced, is the "seivert." This unit is an international unit and is equal to 100 rems.

The Nuclear Regulatory Commission (NRC) and the Environmental Protection Agency (EPA) set and maintain the standards for radiation exposures that members of the public are allowed to receive in addition to background radiation. According to the current standards, individual members of the public may receive up to 100 millirem of radiation annually, excluding medical and dental x-rays, above the amount received as an annual background dose. Within that maximum limit, an individual can receive no more than 25 millirem per year from the disposal of radioactive waste.

Appendix B

Radionuclide Migration and Performance Assessment

Appendix B

Radionuclide Migration and Performance Assessment

Radionuclide Migration

Radionuclides that are not adequately contained can be released from radioactive material or waste and transported through both the geosphere (air, soil, surface water, and groundwater) and the biosphere (plants and animals). Complex interactions may occur as radionuclides migrate through various components in the environment. Doses to humans may occur as a result of direct exposure to natural or manufactured materials that emit radioactivity. These doses may be either external (gamma radiation and surface contact) or internal (inhalation and ingestion) or a combination of the two.

Radionuclide "pathways" which result in human exposure involve a release of radionuclides, coupled with migration through the environment. A simplified diagram of the migration and exposure pathways is presented in Figure B-1.

Figure B-1. Potential radionuclide migration and exposure pathways.

Boxes in the figure represent media that may become contaminated with radionuclides and transport them from one location to another. Arrows indicate mechanisms by which radionuclides may be transferred from one medium to another. "Direct radiation" in this figure implies exposure to direct gamma radiation resulting from immersion in, or proximity to, contaminated materials. Numerous pathways may be traced in this figure. In all cases, with the

exception of direct radiation exposure from the waste, the pathways are composed of an exposure mechanism by which radionuclides released from the waste migrate through one or more media within the environment, and ultimately reach humans.

Direct contact, air contact, and water contact are the three primary exposure mechanisms for low-level radioactive waste at disposal facilities. Direct contact mobilization is caused primarily by human and animal activities that disturb the waste. Wastes brought to the surface by deep rooting plants are also the result of direct contact. Air contact mobilization occurs when waste is exposed to the atmosphere and wind currents mobilize waste particles. Water-contact mobilization results from processes such as dissolution, diffusion, desorption, and ion exchange. Once the waste has been mobilized, the following four primary media exist for transporting radionuclides: air, surface water, groundwater, and food chain.

Facility performance objectives have been established by the Nuclear Regulatory Commission (NRC) for the protection of public health, safety, and environmental resources. These performance objectives require that annual dose equivalents not exceed 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other vital organ of any member of the public. The disposal facility must be sited, designed, operated, and closed to achieve long-term stability and to ensure protection from inadvertent intrusion for these objectives to be achieved.

Performance Assessment

Performance assessment is a systematic analysis of a low-level radioactive waste disposal facility and its surrounding environment, with the intent of demonstrating compliance with established performance objectives. Present conditions and future scenarios must be considered for that period of time in which significant impacts remain a possibility.

The goal of a performance assessment is to calculate potential radioactivity at various human access locations. A description of the physical properties of the low-level radioactive waste disposal facility and its surrounding environment, as well as the kinetic behavior of the environment must be defined. This involves determining potential pathways and specific locations for human exposure to radioactive concentration, development of appropriate scenarios, and the assurance and control of the quality of all data.

A team of technical professionals is required in order to conduct a performance assessment. The qualified team might consist of scientists with backgrounds in hydrology, geochemistry, ecology, geology, and meteorology. Professionals with training in waste management, environmental assessment, mathematics, physics, modeling, and computer programming may also be included.

The performance assessment process includes data collection, model development, and performance assessment calculations. Data requirements include: (a) waste characteristics such as activity, volume, and physical form; (b) physical site characteristics such as size and type of

disposal facility; (c) disposal procedures; (d) biotic considerations such as the composition and abundance of plant and animal communities; and (e) environmental factors including meteorological, geochemical, hydrological, and geologic characteristics.

Once sufficient data have been collected, conceptual models of the disposal system are developed. These models include: (a) a facility model to describe the release of radionuclides within the facility; (b) a transport model to describe the movement of these radionuclides; (c) a demographic model to show the spatial distribution of the human population around the disposal facility; and (d) an exposure model to describe which, and how, receptors become exposed. The conceptual models are eventually translated into mathematical equations and computer programs.

Once appropriate mathematical equations and computer codes have been developed and verified, performance assessment calculations can be performed. Information about waste volume, activity, and radionuclides is input into the computer program. The program creates a simulation of the disposal facility and predicts the radioactivity at various human access locations at various periods of time. The results of the simulation are compared with the performance objectives to determine if the facility's predicted performance meets applicable criteria. If predicted doses to members of the public are less than the applicable regulatory limits, it can be concluded that the facility is in compliance with required performance objectives. In this regard, mathematical models and computer codes generally contain very conservative assumptions. This results in calculated doses much larger than will actually occur. Thus, reasonable assurance is provided that potential exposures to members of the public will be extremely low and well within regulatory limits.

As part of the licensing process, performance assessments will be reviewed by the NRC or the appropriate Agreement State agency to determine the proposed facility's adequacy in demonstrating regulatory compliance. Although not necessarily required, an independent performance assessment may be conducted by the NRC to verify an applicant's calculations.

Appendix C
Disposal Technologies

Appendix C

Disposal Technologies

A typical low-level radioactive waste disposal site includes a restricted area where the waste disposal units and water retention ponds are located, a buffer zone that separates the restricted area from the nonrestricted area, and support facilities required for disposal operations (Figure C-1). The site is designed to accept waste for 20 to 50 years and isolate it from the environment for hundreds of years. The site may vary in size from 25 to 300 acres depending on the disposal concept selected and the expected volume of waste to be disposed. The owner of the site (State or Federal government) may purchase acreage surrounding the site as an additional controlled zone. This brochure describes seven conceptual disposal technologies that have been developed for disposal of low-level radioactive waste. All of the disposal concepts are appropriate for disposal of Class A, B, and C waste. Class B and C waste must be structurally stable (i.e., designed to maintain its dimensions and integrity for at least 300 years).

R94 0617

Figure C-1. Typical low-level radioactive waste disposal site.

Class A waste is not required to be stable by Federal regulations; and, unless it is stable, must be physically separated from stable Class B and C waste for disposal. However, if Class A waste is made stable, then separation from Class B and C waste for disposal is unnecessary.

The Restricted Area is divided into two disposal areas: one for the disposal of waste containing the lowest concentrations of radioactivity (Class A waste), and the other for the disposal of waste containing higher concentrations of radioactivity (Class B and C waste). The area for disposal of Class A waste is the larger of the two areas, because Class A waste comprises about 95% of the total waste volume disposed of at the site.

Both disposal areas are composed of individual Disposal Units, which are defined by physical boundaries that may include walls, floors, trench sides, and earthen covers. Specific characteristics of the unit depend upon the disposal concept chosen for use at the site. Each disposal unit is sized to receive a one-year volume of waste. Upon reaching its filled capacity, the unit is permanently closed. All disposal concepts include devices to monitor moisture in the disposal units and to detect radioactive elements before they have a chance to move from the disposal units.

Retention Ponds are located in the restricted area. The ponds retain collected runoff water from precipitation until it is evaporated by natural mechanisms. Thus, water contact with disposed waste is minimized, and offsite water releases are eliminated.

A Buffer Zone is provided between the unrestricted and restricted area for each disposal concept. Access to the buffer zone is controlled by a guard station. A chain link fence topped with strands of barbed wire provides additional protection against intruders.

Support Facilities, common to each disposal concept, are provided at the disposal site. These include a waste inspection station, truck wash, equipment storage and maintenance building, general warehouse, receiving and decontamination building, and stockpile area for excavated materials. The administration building provides facilities for radiation protection, security, and employee conveniences, as well as a laboratory for analyzing samples. A concrete batch plant and module fabrication building are optional but may be included for disposal concepts that use concrete.

Shallow-land disposal

Shallow-land disposal (SLD) for low-level radioactive waste consists of placing waste containers in an excavated trench (Figure C-2). Voids between containers are backfilled with sand or other suitable material. Each engineered trench is a long, narrow, shallow excavation with a floor, cover, drainage collection, and monitoring system. The trench is closed with an earthen cover to minimize water infiltration and reduce surface radiation exposure.

Figure C-2. Shallow-land disposal.

Intermediate-depth disposal

Intermediate-depth disposal (IDD) for low-level radioactive waste consists of placing waste containers in an excavated trench and backfilling the voids between containers with sand or other suitable materials (Figure C-3). An earthen cover of approximately 32 feet covers the trench. The earthen cover minimizes water infiltration and reduces surface radiation exposure.

IDD is similar to shallow-land disposal except that Class B and C waste is disposed of in deep trenches and protected by an extended cover system.

Figure C-3. Intermediate-depth disposal.

Modular concrete canister disposal

Modular concrete canister disposal (MCCD) for low-level radioactive waste consists of placing waste in reinforced concrete canisters (Figure C-4). Each individual canister is sized to contain the expected packages of waste. Void spaces in each canister are backfilled with grout. The canisters are then placed in shallow trenches below natural grade. Void spaces between canisters are backfilled with sand. The trench is closed by the placement of an engineered cover system to minimize water infiltration and reduce radiation exposures at the surface.

MCCD differs from shallow-land disposal in that concrete canisters are used to provide additional structural stability.

D94 0136

Figure C-4. Modular concrete canister disposal.

Aboveground vault

Aboveground vault (AGV) disposal for low-level radioactive waste consists of placing waste in an engineered concrete vault and backfilling voids between containers with sand (Figure C-5). A concrete roof is poured in place over each backfilled cell to close the disposal unit. The AGV concept does not employ an earthen cover system; the facility relies on the ability of the concrete structure to isolate the waste from the surrounding environment. AGV differs from other disposal concepts in that the vault is located above the natural grade of the disposal site and does not use an earthen cover system.

Figure C-5. Aboveground vault.

Belowground vault

Belowground vault (BGV) disposal for low-level radioactive waste consists of placing the waste in an engineered concrete vault located below the natural grade of the disposal site (Figure C-6). The reinforced concrete structure consists of floors, walls, and a roof. Waste is stacked in the vault; voids between waste containers are backfilled with sand and compacted. The concrete roof is poured in place, and the vault is capped with an earthen cover. The earthen cover minimizes water infiltration and reduces surface radiation exposure.

BGV differs from shallow-land disposal in that concrete structures are used as engineered enhancements. These enhancements provide additional structural stability to the disposal unit and reduce surface radiation levels.

Figure C-6. Belowground vault.

Earth-mounded concrete bunker

The earth-mounded concrete bunker (EMCB) disposal concept for low-level radioactive waste combines the use of two disposal concepts in the same disposal unit: the belowground vault and modular concrete canister concepts (Figure C-7).

Class B and C waste is disposed of in a concrete bunker below the natural grade of the disposal site. Waste is placed in the concrete bunker, and voids between waste containers are backfilled with concrete. A concrete roof is poured to form a "monolith" upon closure.

Class A waste is placed in reinforced modular concrete canisters and stacked over the concrete bunker above the natural grade of the disposal site. Voids between canisters are backfilled with sand or other suitable materials and covered with an engineered earthen cover to form a "tumulus." The earthen cover minimizes water infiltration and reduces surface radiation exposure.

The EMCB concept differs from shallow-land disposal in that Class A waste is disposed of with Class B and C waste in the same disposal unit since the reinforced modular concrete canisters provide structural stability for Class A waste, similar to the structural stability needed for Class B and C waste.

Figure C-7. Earth-mounded concrete bunker.

Earthen-covered abovegrade vault

Earthen-covered abovegrade vault disposal technology involves isolating low-level radioactive waste in an engineered vault located above the natural grade of the disposal site (Figure C-8). A multilayer, engineered earthen cover is positioned over the vault to provide an additional barrier. Class A waste that does not meet the stability requirements for Class B and C waste will be segregated at the time of disposal and isolated in separate waste disposal units.

An alternative disposal concept using this technology involves placing all waste into reinforced modular concrete canisters before placement in the vault. this would provide structural stability for the waste, which could allow Class A, B, and C waste to be disposed of in the same disposal unit.

Figure C-8. Earthen-covered abovegrade vault.

Disposal operations

The earthen-covered abovegrade vault disposal facility illustrates the various operational stages at a low-level radioactive waste disposal facility. This theoretical disposal facility holds five disposal units (Figure C-9).

The buildings shown at the front of the illustration represent an administration building on the right and a technical services building on the left of the entrance road. A security and inspection station is located at the entrance to the secured disposal area. Two buildings are located within the secured area — one for unloading waste, and another for maintenance.

The illustration includes two water retention ponds, one at the back of the facility and one at the lower left corner. Both ponds will collect runoff from precipitation.

The illustrated facility is encircled by an additional controlled zone.

Figure C-9. Disposal operations.

Unit 1

Unit 1 demonstrates the various disposal stages for Class B and C waste. Each small-volume disposal vault is positioned on the concrete platform, as shown on the smaller front pads. The concrete pad just above holds four disposal cells. The center pad displays a cutaway of a multi-layer, earthen-covered abovegrade disposal vault. The top two pads are completed, earthen-covered abovegrade disposal vaults.

Unit 2

Unit 2 represents the preparation stage of developing a disposal unit for Class A waste. This earthen pad forms the foundation for a concrete disposal pad and an environmental monitoring system.

Unit 3

Unit 3 shows the active disposal phase of a disposal unit. A series of disposal cells are constructed on the pad. Each pad may host 20 disposal cells, which will be filled with waste one at a time and then closed. A temporary movable shelter provides cover from the weather during waste placement and closure of each disposal cell.

Unit 4

Following closure of all cells located on a disposal pad, the unit is covered with a multi-layer, engineered earthen cover. A cut-away of the earthen cover is illustrated in Unit 4.

Unit 5

Unit 5 depicts a completed, earthen-covered abovegrade vault during the long-term monitoring and observation period.