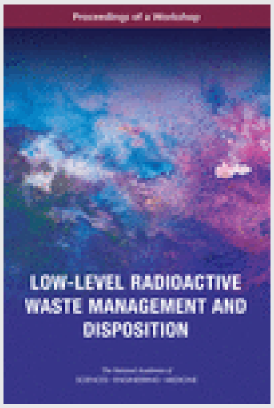

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LOW-LEVEL RADIOACTIVE WASTE MANAGEMENT AND DISPOSITION

Proceedings of a Workshop

Jennifer Heimberg, *Rapporteur*

Planning Committee on Low-Level Radioactive Waste Management and Disposition: A Workshop

Nuclear and Radiation Studies Board

Division on Earth and Life Studies

The National Academies of
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This Proceedings of a Workshop was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published Proceedings of a Workshop as sound as possible and to ensure that the Proceedings of a Workshop meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the process. We wish to thank the following individuals for their review of this Proceedings of a Workshop:

- John S. Applegate, Indiana University
- Miklos (Mike) Garamszeghy, Canadian Nuclear Waste Management Organization (NWMO)
- Christine Gelles, Longenecker and Associates
- Roger Seitz, Savannah River National Laboratory
- Mark Yeager, South Carolina Department of Health and Environmental Control

Although the reviewers listed above have provided many constructive comments and suggestions, they did not see the final draft of the Proceedings of a Workshop before its release. The review of this Proceedings of a Workshop was overseen by Patricia J. Culligan, Columbia University. She was responsible for making certain that an independent examination of this Proceedings of a Workshop was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this Proceedings of a Workshop rests entirely with the rapporteur and the institution.

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1

Introduction

The Department of Energy's Office of Environmental Management (DOE) is responsible for the safe cleanup of sites used for nuclear weapons development and government-sponsored nuclear energy research. Established in 1989, DOE's cleanup program originally encompassed more than 100 sites. Cleanup is planned to last another 40-50 years with total lifecycle costs approaching or exceeding $350 billion. The annual cleanup budget is around $6 billion.[1]

Low-level radioactive waste (LLW[2]) is the most volumetrically significant waste stream generated by the DOE cleanup program (approximately 17 million cubic meters per year[3]). LLW is also generated through commercial activities such as nuclear power plant operations and medical treatments. DOE disposes of LLW at its own sites as well as at some commercial facilities. Commercial LLW is, with some exceptions, disposed of at commercial facilities.

In the United States, LLW is not necessarily defined by low levels of radioactivity. The Low-Level Radioactive Waste Policy Amendments Act of 1985 (LLRWPA amendments[4]) defines LLW as

[1]This value is an average of the past four annual budgets for DOE's Office of Environmental Management (Regalbuto, 2016).

[2]"LLW" and "LLRW" are commonly used acronyms for low-level radioactive waste. "LLW" is used throughout this proceedings unless "LLRW" is included in a quote from other sources.

[3]This average was calculated from a DOE complex-wide disposal rate for LLW and mixed LLW (Marcinowski, 2016). LLW containing hazardous chemicals is referred to as mixed LLW.

[4]"Low-Level Radioactive Waste Policy Amendments Act of 1985," accessed February 24, 2017, https://www.gpo.gov/fdsys/pkg/STATUTE-99/pdf/STATUTE-99-Pg1842.pdf.

low-level radioactive material that:

(A) is not high-level radioactive waste, spent nuclear fuel, or byproduct material (as defined in section 11.e (2) of the Atomic Energy Act of 1954 . . . [[5]]); and

(B) the Nuclear Regulatory Commission, consistent with existing law and in accordance with paragraph (A), classifies as low-level radioactive waste.

Thus, LLW is defined by exclusion (i.e., by what it is not).[6] LLW is physically and chemically diverse, ranging from lightly contaminated soils and building materials to highly irradiated nuclear reactor components.

The laws and regulations related to the disposal of LLW in the United States have evolved over time and across agencies and states (see Box D-2 in Appendix D), resulting in a complex regulatory structure. This structure has provided adequate guidance for the successful disposal of the majority of LLW streams, but there are some types of LLW streams—many of which were not anticipated when LLW regulations were created—that lack an obvious pathway to disposal or whose disposition could be considered incommensurate with the hazard of the waste. "Challenging LLW streams," as used in this proceedings, have potentially non-optimal or unclear disposition pathways due to their origin, content, or incompatibility with existing standards, orders, or regulations.

DOE asked the National Academies of Sciences, Engineering, and Medicine (National Academies) to organize this workshop to discuss approaches for the management and disposition of LLW. The workshop explored the following two issues:[7]

- the key physical, chemical, and radiological characteristics of LLW that govern its safe and secure management and disposal in aggregate and in individual waste streams, and
- how key characteristics of LLW are incorporated into standards, orders, and regulations that govern the management and disposal

[5] "[B]yproduct material . . . as defined in Sec. 11.e (2)" is provided in the Atomic Energy Act of 1954 as amended: "Sec. 11 DEFINITION . . . e. The term 'byproduct material' means . . . 2) the tailings or wastes produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content. . . ." See "Atomic Energy Act of 1954 as amended by Public Law 114-92, Enacted November 25, 2015," accessed March 1, 2017, https://legcounsel.house.gov/Comps/Atomic%20Energy%20Act%20Of%201954.pdf.

[6] The definition of LLW is complicated, requiring one to understand the definitions of other waste categories such as high-level radioactive waste and byproduct material. The full list of byproduct materials as well as definitions of other waste categories mentioned in this chapter are provided in Appendix D, Box D-1.

[7] Appendix A contains the full statement of task.

of LLW in the United States and in other major waste-producing countries.

This proceedings provides a factual description of the workshop presentations and discussions and is limited to the views and opinions of those participating in the event. Further, the viewpoints and comments from the workshop attendees are their own and are neither necessarily attributable to the organizations for which they work or support nor necessarily representative of the views of all workshop participants, the planning committee, or the National Academies. This proceedings does not contain consensus findings or recommendations.

1.1 WORKSHOP PLAN

A committee of four members was appointed by the National Academies to plan the workshop.[8] The planning committee met once to develop the workshop format and agenda and to identify speakers. In addition, a white paper developed by the rapporteur was distributed to participants prior to the workshop to provide background information on LLW.[9] The workshop was held at the National Academies' Keck Center on October 24-25, 2016.

The workshop began by defining the "universe" of LLW within the United States and elsewhere—first by introducing the types of LLW that exist and then by discussing the standards, orders, regulations, and laws that define and control their disposal. Next, case studies were presented to highlight the successful disposal of a variety of wastes that previously lacked a clear disposition pathway—these case studies are referred to as "success stories." The studies were selected from within and outside of the United States.

The participants explored common themes that led to success within the case studies such as: the use of existing regulations and standards (i.e., waste classification) to provide an anchor for disposal decisions; the identification of lessons learned from similar or analogous problems such as Canada's or France's approach to managing and disposing of very low-level waste (VLLW); and the importance of site characteristics for disposal decisions. These themes were organized into an approach to guide future discussions and disposition decisions for challenging LLW streams—a "common themes approach."[10] The approach is described in Chapter 4.

[8]The planning committee's role was limited to planning and participating in the workshop. See Appendix B for the planning committee member biographies.

[9]The workshop agenda and white paper can be found in Appendices C and D, respectively.

[10]The "common themes approach" was developed as a discussion tool; it was not intended or presented as a consensus statement by the planning committee or the workshop participants.

The common themes approach was applied to a set of five pre-selected challenging LLW streams that spanned a variety of waste characteristics:

- Greater-Than-Class C (GTCC) and commercial transuranic waste (TRU) waste in excess of 100 nCi/g
- Sealed Sources
- Very Low-level and Very Low-activity Waste[11]
- Incident Waste
- Depleted Uranium

Each of these waste streams presents a unique set of challenges for disposal. For example, "GTCC waste and commercial TRU waste in excess of 100 nCi/g" lack a clear disposition pathway (as will be discussed in Chapter 4), while "Very Low-level and Very Low-activity Waste" have a disposition pathway in which the level of protection may be considered incommensurate with the hazard, or a potentially non-optimal disposition pathway (discussed in Chapters 2 and 4). The application of the common themes approach to these diverse waste streams was intended to explore how adaptable this approach would be as a tool in discussing or presenting a variety of disposal options.

One leader from each breakout group introduced a specific challenging LLW stream to the full workshop and later summarized the breakout group's results of applying the common themes approach to the issues associated with the disposal of this waste stream. Several participants identified short-term actions or "next steps" that could be taken to show progress in addressing each challenging waste stream in the final session of the workshop.

Presenters and attendees provided perspectives from academia, industry, federal agencies (including those outside of DOE), state governments, international organizations, public interest groups, and national laboratories. All participants were encouraged to contribute to the workshop discussions.

Several major topics emerged during the discussions throughout the workshop: complexity of regulations; communication among stakeholders; diversity of the type, source, and hazard of LLW; and integration of knowledge gained from operations. These topics are described below.

1.2 COMPLEXITY OF REGULATIONS

The complexity of the current U.S. LLW regulatory structure was mentioned in several presentations and discussions. Participants noted that the current regulatory structure is the result of "tweaks" and "adjustments"

[11]The planning committee proposed "exempt waste" as a category for the subgroup, but the topic of the subgroup's discussion focused on very low-level waste and very low-activity waste.

to regulations to address unanticipated types of wastes or other challenges. Several participants argued that the current LLW regulatory system should be thrown out and that a new system should be "developed from scratch." This "revolution instead of an evolution" of the LLW regulatory structure was raised several times during the workshop. Participants also discussed the complexity of the definition and regulation of TRU waste, noting that multiple laws and regulations contain definitions of TRU waste that can be inconsistent with each other.[12] It was also noted that the current LLW regulatory system has the flexibility to deal with unanticipated waste streams through case-by-case exceptions—which adds to the system's complexity. The unintended impacts of this complex system include the following: potential loss of public trust and confidence; mounting costs for disposal that are passed on to rate payers; and levels of regulation that are disproportionate to the hazards posed by LLW.

1.3 COMMUNICATION AMONG STAKEHOLDERS

Several participants noted that the complexity of the current LLW regulatory system leads to communication problems with stakeholders. Many stakeholders assume that LLW must be dangerous because the regulations are so strict and complex.

The appropriateness of the language used when discussing stakeholder or public concerns was also questioned by several participants. Some noted a move away from the use of "stakeholder"—which is a term that is difficult to define—to "concerned" or "interested parties" to be inclusive of a wider group including waste producers, academics, and other members of the public. Other phrases often used by experts that raise concern include: "Talking to the public," which implies a one-way flow of information, instead of "talking with the public." Or "educating the public," which was identified as denigrating; its use presupposes that the public is uneducated and also that, if given education, the public would agree with the experts doing the educating. Improving communications among stakeholders involves a change in mindset in addition to a change in language. Decisions on the final disposition of challenging wastes could be informed by a continuing conversation with stakeholders throughout the lifetime of a project.

[12]The Waste Isolation Pilot Plant Land Withdrawal Act provides the definition for defense TRU waste. The USNRC's document, *Statutory Language and Regulatory History of Commercial Transuranic Waste Disposal* (USNRC, 2015a), provides an example of conflicting definitions of TRU waste, which highlights the complexity of the topic (p. 5): "According to section (A)(i) of the [Low-level Radioactive Waste] Amendments Act, TRU waste is LLRW. Based on (A)(ii) of the Amendments Act, the [US]NRC can set the definition of LLRW. Consistent with (A)(ii) of the Amendments Act and because the 10 CFR Part 61 definition of LLRW excludes TRU, TRU is not LLRW."

The topic of accepting responsibility for the waste streams now to ensure safe disposal for future generations was repeatedly discussed at the workshop. Several participants noted that discussions with stakeholders on the final disposition of LLW were aided when the origins and social value of the activities that produced the wastes (i.e., medical treatments, electricity generation) were described.

1.4 DIVERSITY OF LOW-LEVEL WASTE TYPE, SOURCE, AND HAZARD

Participants noted that the "universe" of LLW in the United States is large due to its definition by exclusion. In the United States, high-activity wastes such as irradiated metals and sealed sources of high activity are considered LLW. Also, very low-activity wastes in the United States are subject to disposal requirements that many participants believed exceeded the hazard of the waste. Participants noted that characteristics such as half-life and activity levels (or hazards) of the waste are used in other countries to define waste categories and disposal options. Participants also noted that other countries have a "cleared" or "exempt" category of waste that allows for less protective disposal—an approach that is commensurate to the hazard of the waste—while there is no low-end threshold of activity for LLW in the United States. Also, in the United States, the states have regulatory authority for some radioactive wastes and regulations can be inconsistent across state boundaries even though the characteristics and hazard of the waste remain the same.

1.5 INTEGRATION OF KNOWLEDGE GAINED FROM OPERATIONS

The United States and other countries have been managing and disposing of nuclear waste for at least six decades. Several comparisons of early to modern LLW disposal concepts and facilities were presented at the workshop including: the EnergySolutions LLW Disposal Facility, Barnwell (South Carolina), Waste Control Specialists (Texas), and the Centre de la Manche (CSM) and Centres de stockage de l'Aube (CSA) (France) disposal facilities. These comparisons highlighted the improvements in modern facilities that resulted from applying the knowledge gained from the construction and operation of earlier facilities. Another point that was repeatedly raised by participants at the workshop was the importance of site characteristics of modern facilities in the United States, many of which are located in arid regions of the country. Several participants noted that the United States should find a way to integrate this new knowledge into the regulations and rules that govern the management and disposal of LLW.

1.6 ORGANIZATION OF THE PROCEEDINGS

This proceedings is organized following the general structure of the workshop:

- Chapter 2 includes introductory remarks by the chair and an overview of the scope of the LLW challenge (or the "universe" of LLW),
- Chapter 3 presents the case studies of successful LLW disposition,
- Chapter 4 identifies common themes for finding successful disposition solutions, applies them to a set of five challenging LLW streams, and summarizes concrete next steps towards a disposition pathway that might be taken for each.

2

Describing the Universe of Low-Level Waste

John Applegate, the planning committee chair and executive vice president for University Academic Affairs of Indiana University, welcomed the workshop attendees and provided short introductory remarks prior to initiating the panel presentations and discussions. His remarks are summarized below.

The workshop's objective was to identify approaches that might facilitate the disposition of challenging low-level waste (LLW) streams. These proceedings define "challenging LLW streams" as LLW streams that have potentially non-optimal or unclear disposition pathways due to their origin or content and incompatibility with existing standards, orders, or regulations. These approaches could possibly be used by the Department of Energy (DOE), the U.S. Nuclear Regulatory Commission (USNRC), U.S. states, and others to find safe and acceptable disposition pathways for challenging LLW streams.

Two critiques of the current U.S. LLW regulatory system have significance for this workshop: The first is that the U.S. LLW category is broad and provides limited guidance for dispositioning unusual or unanticipated LLW waste streams. The second is that standards, orders, and regulations tied to the management and disposition of LLW are not sufficiently tied to risk.

With respect to the first critique, the LLW category is defined by exclusion.[1] LLW is *not* high-level radioactive waste, spent nuclear fuel, or

[1]See Chapter 1 for a discussion on the statutory definition of LLW. Also, Appendix D, Box D-1 provides a more detailed definition.

uranium or thorium mill tailings and waste (also referred to as "11.e (2) byproduct material"[2]). Consequently, the LLW category covers a wide and very heterogeneous range of waste streams and, also, disposal requirements.

The fundamental problem with a broad LLW category is the lack of specific guidance for unanticipated LLW streams. Waste generators want to be able to plan for waste disposition; they need to know where their waste will go for disposal, how it needs to be processed and managed to make it acceptable for disposal, how to get it to where it is going to be disposed of, and how much it will cost. The waste recipients (i.e., the operators of disposal facilities and their stakeholders) also need to plan for acceptance of the waste; they want to know what the regulatory requirements are for acceptance; and they want to be able to reassure their stakeholders about the safety of waste disposition. One solution to the problem of unanticipated waste streams is to create new waste classifications that include them. Another option is to use case-by-case exceptions that are based on specific and known criteria and that can be applied in a consistent and predictable way.

With respect to the second critique, that LLW disposition regulations are not consistently tied to the risk, National Academies reports have consistently recommended that disposal of LLW focus on risk as opposed to waste origins.[3] These reports have urged greater attention to risk and a closer relationship between risk and regulatory requirements in the management of radioactive waste.

The report *Improving the Regulation and Management of Low Activity Radioactive Waste* (National Research Council, 2006b) concludes that a risk-informed approach provides the best option for improving the regulation and management of low-activity waste.[4] However, the current LLW regulatory system in the United States is based primarily on waste origins rather than risk. The report found that certain categories of low-activity waste have not received consistent regulatory management, and that current regulations for low-activity waste are not based on a systematic consideration of risk. The report acknowledged that changes to the regulatory structure would likely take many years, require coordination among many federal and state agencies, be highly individualized, and would need many assessments of individual situations. The report recommended adopt-

[2]"[B]yproduct material…as defined in Sec. 11.e (2)" is provided in the Atomic Energy Act of 1954 as amended. See "Atomic Energy Act of 1954 as amended by Public Law 114-92, Enacted November 25, 2015," accessed March 1, 2017, https://legcounsel.house.gov/Comps/Atomic%20Energy%20Act%20Of%201954.pdf.

[3]See National Research Council 1997, 2000, 2001, 2005, 2006a, 2006b, and 2011a.

[4]The term "low-activity waste" in these proceedings refers to waste having very low radioactivity. This is different from DOE's use of "low-activity waste," which refers to a component of tank waste that is not highly radioactive.

ing a tiered approach, identifying a set of changes that could be implemented in order of increasing complexity, resources, and time, to make progress toward converting the current regulatory system into one that is risk-informed.[5]

The objective of LLW regulations is to protect human health and the environment, so consideration of risk is likely to be an important focus of the discussions in the present workshop. Human health effects of radiation are one important aspect of risk. Other factors that contribute to risk include fate and transport of contaminants, site geology, institutional controls, and the longevity of engineered barriers of disposal facilities.

Mr. Applegate asked the participants to balance the two aforementioned critiques against the following. First, the regulatory system reflects the problems it was originally created to solve. As the problems are better understood and/or change over time, the regulations must be adjusted accordingly, resulting in increased regulatory complexity. Challenging LLW streams are examples of such changing problems. New challenging LLW streams can be treated as exceptions to existing regulations and addressed in a case-by-case manner, or regulations can be modified to address them. In any case, the decision-making process is time-consuming, not standardized or predictable, and inconsistent across regulatory agencies, states, or even within individual agencies. Nor do these approaches leverage experience from previous cases.

Second, despite its complexity, the United States has a system for regulating the disposal of LLW that works well in the great majority of cases as demonstrated by the large volumes and variety of LLW streams that have been efficiently and successfully disposed of. However, the challenging LLW streams are not trivial—by volume and/or hazard—and many of these waste streams attract controversy when decisions are made regarding storage, transportation, and disposal. Therefore, one of the goals of the workshop is to examine the methods for addressing such waste in a rational, consistent, and coherent way.

Mr. Applegate ended his introductory remarks with a charge to the workshop attendees. We should ask ourselves questions such as the following: Should there be new classifications for these challenging waste streams? Should we develop criteria for a "below regulatory concern" LLW waste classification? Do we need new regulatory classifications and/or subcategories for LLW? Should those classifications or categories be differentiated from each other by source, risk, and/or inherent characteristics? We should consider how to balance flexibility and individual tailoring of a

[5]Specifically, Recommendation 2 in the report suggests "a four-tiered approach: (1) changes to specific facility licenses or permits and individual licensee decisions; (2) regulatory guidance to advise on specific practices; (3) regulation changes; or if necessary, (4) legislative changes" (National Research Council, 2006b, p. 7).

particular waste stream against predictability and consistency of the regulatory system.

2.1 THE SCOPE OF THE LLW CHALLENGE

The first session of the workshop consisted of two panels.

- The first panel focused on categories and characteristics of LLW; it was moderated by Nina Rosenberg, a member of the workshop planning committee and program director at Los Alamos National Laboratory.
- The second panel focused on the regulations, standards, orders, and guidance that have been developed for LLW; it was moderated by Larry Camper, also a member of the workshop planning committee and recently retired from the USNRC.

The moderators opened each panel with brief presentations of background information, which are summarized below. Invited panelists then presented more detailed information on specific topics. A discussion was held after each panel.

The comments from the moderators, panelists, and other workshop participants are their own. They do not necessarily represent official views of their employers, governments, or other organizations that may be mentioned in their presentations and discussions.

2.2 CLASSIFICATION, CATEGORIES, AND CHARACTERISTICS OF LLW

Dr. Rosenberg moderated the session on the classification, categories, and characteristics of LLW. Her remarks are below. She reminded the participants that, in the United States, LLW is defined "by exclusion." Civilian (usually commercial) LLW is regulated by the USNRC based on specific activity concentrations of radionuclides deposited in a waste matrix and intended for final disposition: Classes A, B, C, and Greater-Than-Class C (GTCC), with Class A requiring the lowest and GTCC requiring the greatest levels of protection (see Tables D-1 and D-2). Near-surface disposal is appropriate for Class A, B, and C wastes but is not appropriate for GTCC wastes.[6] There are currently four commercial sites for LLW disposal using near-surface disposal methods in the United States; they are located in Utah, Texas, South Carolina, and Washington. These facilities are constructed to

[6]The disposal of GTCC is a federal responsibility.

meet generic performance objectives defined by USNRC regulations and have defined waste acceptance criteria.

Government-owned LLW[7] is regulated by DOE. It is DOE policy to dispose of these wastes if possible at the sites where they were generated or are stored. There are currently four DOE sites that dispose of their own wastes: Idaho National Laboratory, Oak Ridge National Laboratory in Tennessee, Savannah River Site in South Carolina, and Los Alamos National Laboratory (Area G) in New Mexico. Two additional DOE sites dispose of offsite LLW in addition to their own wastes: US Ecology, Inc., LLW Disposal Facility at the Hanford Site, Washington, and the Nevada National Security Site (NNSS, previously named the Nevada Test Site). DOE relies on waste acceptance criteria derived from site-specific performance assessments to manage and dispose of LLW at all of its facilities. These DOE facilities use a variety of near-surface disposal methods with engineered structures and surface barriers, depending on site characteristics and waste acceptance criteria.

Both the DOE and commercial sites listed above are located in different climate zones, varying from very wet and humid (South Carolina and Tennessee) to very dry and arid (New Mexico, Nevada, Idaho, Texas, Utah, and eastern Washington). Further information about these sites can be found in Appendix D.

International schemes for managing LLW differ from U.S. approaches in some important ways. The International Atomic Energy Agency (IAEA) bases its guidance[8] on radioactive waste classification on disposal considerations in six categories from exempt, very short-lived waste, VLLW, LLW, intermediate-level waste, and high-level waste.

Three panelists having different backgrounds and with different perspectives were invited to discuss LLW types. They were specifically asked to address the following two questions:

- What are the greatest challenges that you have observed in the management of LLW?
- What key technical criteria and/or waste characteristics are most important to consider in the management and disposal of these wastes?

Miklos (Mike) Garamszeghy, design authority and manager of technology assessment and planning for the Canadian Nuclear Waste Management Organization (NWMO), provided a Canadian perspective; Lisa Edwards,

[7]This has previously been referred to as "defense LLW."

[8]The IAEA provides guidance on the regulation—but does not regulate—the nuclear wastes of its member states.

senior program manager for Electric Power Research Institute (EPRI),[9] provided perspectives from the commercial nuclear industry (as waste generators); and Daniel (Dan) Shrum, senior vice president of regulatory affairs at EnergySolutions, provided perspectives from the U.S. commercial disposal industry.[10]

LLW Challenges—The Canadian Context

Mr. Garamszeghy began his presentation by describing the main difference between the U.S. and Canadian approaches to the management of LLW: in Canada, waste owners are responsible for managing their own waste, from generation to disposal. There is no national organization that looks after waste disposal, but there is a national regulator. Similarly, there are no commercial entities whose sole focus is waste disposal.

Prior to 2008, the Canadian radioactive waste classification scheme was similar to that for the United States—defining LLW by exclusion and using the following waste categories: nuclear fuel waste (used fuel), uranium mining and milling waste, and LLW (everything else). The current classification scheme, established in 2008, follows the IAEA's *General Safety Guide GSG-1* (IAEA, 2009a) for establishing waste categories: exempt, VLLW, LLW, intermediate-level waste, and high-level waste. The Canadian scheme does not establish numerical boundaries between the different waste classes; the values of the boundaries are determined and justified by the waste owners. This classification scheme provides consistency in terms of the IAEA terminology, but the actual distinction between different waste classes is less clear.

Unlike the U.S. approach, the system in Canada allows clearance of waste through the exempt category. Waste can be exempted in two ways: A generic regulation allows waste to be cleared if its activity is below a very conservative limit based on IAEA's *Safety Guide RS-G1.7* (IAEA, 2004). Alternatively, for wastes having slightly higher activities, waste owners may perform case-by-case analysis for the higher limit.

Canada's VLLW and LLW are currently generated from a number of sources, similar to waste generation in the United States. Waste characteristics vary widely based on waste source. Intermediate-level waste, for example, is generated by day-to-day operations at nuclear power plants (NPPs); refurbishment and decommissioning of power reactors; and isotope production.

Mr. Garamszeghy provided the following list of questions that are typically considered by waste owners in Canada when making decisions on the disposition of their radioactive waste:

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[9]EPRI is a nonprofit research entity supported by the electricity industry.

[10]The biographies for the speakers and panelists can be found in Appendix E.

- What type of waste needs disposal?
- Who owns the waste?
- How much waste is there?
- Where is the waste located?
- What are the community preferences?
- What are the total system costs for managing the wastes?
- What other hazards are associated with the waste?
- How is the waste currently packaged and stored?
- How well is the waste characterized?

Mr. Garamszeghy noted that Canada does not currently have any licensed and operational disposal facilities for low- and intermediate-level waste or spent fuel. However, a number of facilities are in various stages of licensing or construction. In Canada, the NWMO has the mandate for the long-term management, including disposal, of spent fuel. There is no national entity for disposal of low- and intermediate-level waste, as mentioned at the start of his presentation. All of the waste is stored by the waste owners in facilities of various designs (i.e., above and below ground) and locations. Figure 2-1 is a map that shows the locations of some of these facilities. Note that these facilities are distributed throughout Canada.

Overview of Commercial Power Plant Wastes

Ms. Edwards' presentation focused on LLW produced by U.S. NPPs. Two types of wastes are produced, dry active and wet waste. Dry active waste consists predominantly of papers, plastic, and cloth, for example the protective clothing worn in facilities. It can also include tools, wiring, and metals that are not compactable. Wet waste is principally made up of resin, charcoal, and filters. Wet wastes are generated during NPP operations, primarily during the cleanup of water systems. Boiling water reactors also produce irradiated hardware LLW streams; however, this waste stream is not included in this discussion because it represents a small fraction of waste.

Figure 2-2a shows the volume of waste types (i.e., dry active and wet wastes) generated by U.S. NPPs between 2003 and 2007; and Figure 2-2b shows the volume of resin wastes generated during this same time period grouped by USNRC waste class (i.e., Class A, B, or C). It is clear that the vast majority (almost 90 percent) of the waste generated is dry active waste or Class A waste. Class B waste is 13 percent, and Class C is 1 percent of the total (Figure 2-2b).

At the time these data were collected, filters made up almost the entire volume of Class C waste, and resins made up the majority of Class B waste. However, once NPPs implement the new concentration averaging requirements from the updated USNRC *Branch Technical Position on Concentra-*

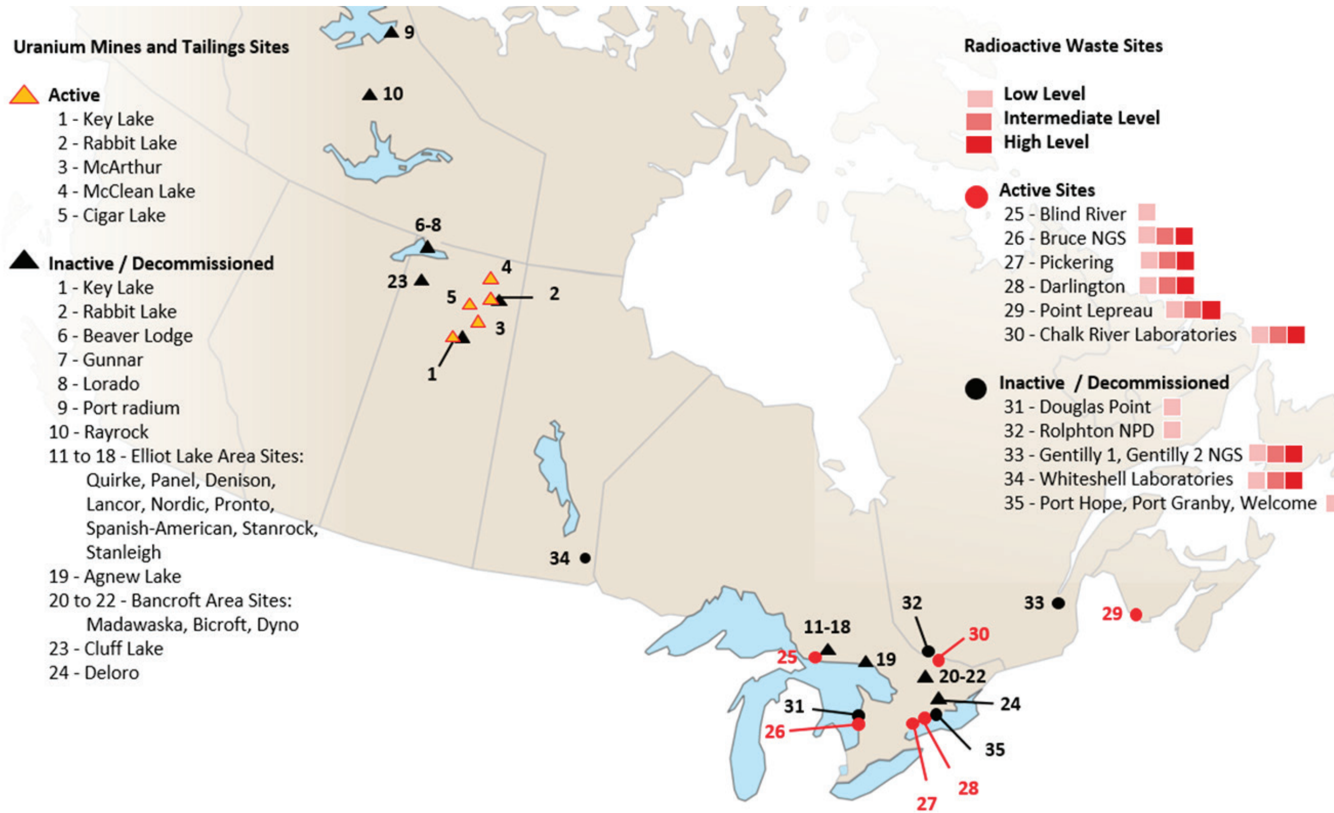
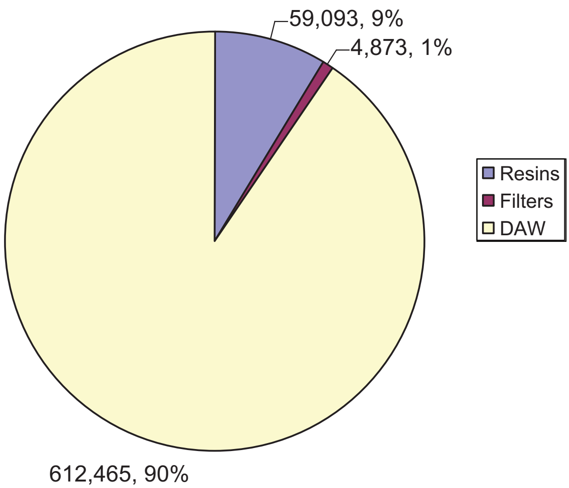


FIGURE 2-1 Major radioactive waste management sites in Canada.
SOURCE: Canadian Nuclear Safety Commission.

(a) Average Annual Waste Volumes for 65 Plants (ft^3) by Waste Type



(b) Average Annual Resin Waste Volume (ft^3) for 65 Plants by Waste Class

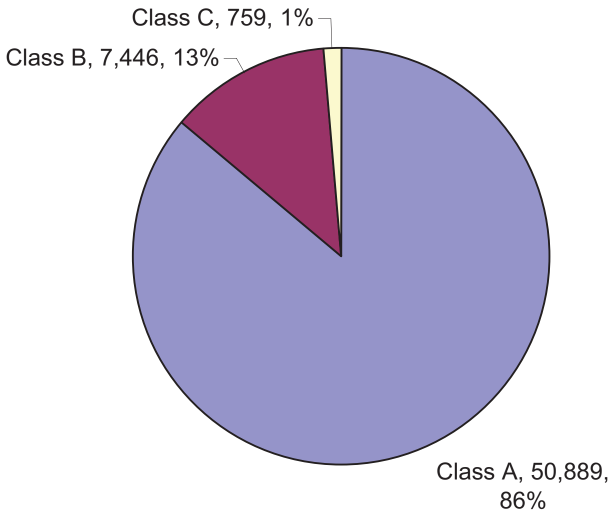


FIGURE 2-2 Historic average annual waste volumes by (a) waste type and (b) waste class (volumes listed in cubic feet).
NOTE: DAW refers to dry active waste.
SOURCE: Courtesy of the Electric Power Research Institute.

tion Averaging and Encapsulation,[11] it is likely that Class C waste will become virtually nonexistent outside of irradiated hardware. Ms. Edwards suggested that the combined Class B and C slice of the pie (Fig. 2-2b) may approach zero once concentration averaging is implemented.

Recent data from an EPRI database, RadBench,[12] show the trends in the generation of dry active and wet wastes from NPPs. There has been a steady reduction in dry active waste (at a rate of approximately 10,000 pounds per year) beginning in 2008. For wet wastes, there was a slight reduction between 2007 and 2011 followed by a near-equivalent increase. The reduction may have occurred for two reasons: (1) the LLW disposal site at Barnwell, South Carolina, stopped accepting LLW from all states except those within its compact,[13] and (2) an EPRI report (Edwards, 2010) released near this time highlighted techniques and practices for reducing the volume of Class B and greater operational waste (which is primarily wet waste). The volume of wet waste began to increase in 2011 when the Waste Control Specialists (WCS) facility in Texas was licensed and began accepting LLW.

LLW management and disposition do not affect the generation of electricity and are not a NPP's primary business. The managers of NPPs make disposal decisions based on the most economical and safe alternatives. The cheapest option that meets safety (and other) disposal requirements is nearly always selected. A rough analogy is the choice that a member of the public makes on who picks up his/her household garbage. The individuals responsible for the packaging and management of radioactive waste are internally motivated; other plant workers may not understand the potential impact of waste management mistakes. Those individuals who are involved in waste management consider themselves to be the environmental guardians of the plant, making sure the NPPs do not encounter problems over the waste management and disposition decisions.

Ms. Edwards noted the lack of a "very low-level waste" category in the U.S. regulatory system but its inclusion in the classification systems of other countries such as Canada. VLLW is defined differently throughout the world, but it is generally characterized as having a very small percentage of the activity defined by other waste class limits and a very low radiation hazard.

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[11]For more details on concentration averaging, see "Branch Technical Position on Concentration Averaging and Encapsulation," last updated October 26, 2016, https://www.nrc.gov/waste/llw-disposal/llw-pa/llw-btp.html.

[12]RadBench is used by NPPs around the world to self-report the volumes of waste that they generate, prior to conditioning and disposal. The disposal volumes may be smaller. See "EPRI Product Abstract: WasteLogic RadBench Web Application (RadBench) v3.0.2," accessed March 1, 2017, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002003994.

[13] See Appendix D for a brief explanation of the U.S. state compact system.

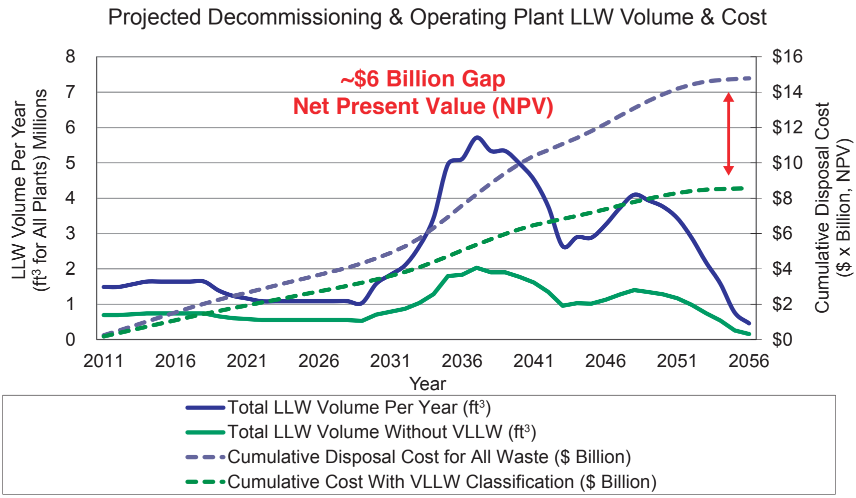

FIGURE 2-3 Potential very low-activity waste cost savings projections. The solid blue line respresents the projected volume of LLW through 2056 that will be produced as NPPs are decommissioned. The solid green line represents the projected volume of LLW minus the lowest activity fraction. The dotted blue and green lines are cumulaitve disposal costs. The difference between the blue and green dotted line by 2056 is roughly $6 billion. The projections for decommissioning wastes change nearly yearly, so the estimates in this figure should be considered rough.
NOTE: ft^3 = cubic feet; LLW = low-level waste; NPV = net present value; VLLW = very low-level waste.
SOURCE: Courtesy of the Electric Power Research Institute.

A strong argument can be made that U.S. regulatory requirements for wastes classified as very low-level (or very low-activity) in other countries are overly burdensome and costly (see Figure 2-3) (EPRI, 2012). Very low-activity waste makes up approximately 80 percent of the volume of waste that is generated during NPP decommissioning; the cost of decommissioning is passed along to the public.

There are regulatory pathways for reducing the costs of disposing of this very low-activity waste, even though a VLLW category does not exist in the United States. For example, an exemption under the USNRC's *Code of Federal Regulations 10 CFR* 20.2002 (referred to as the "20.2002 exemption")[14] allows for specific waste streams to be approved for disposal

[14]A brief explanation of the exemption is provided on the USNRC's website: "10 CFR 20.2002 is available for use by licensees for wastes that typically are a small fraction of the

at Resource Conservation and Recovery Act (RCRA) disposal sites instead of LLW-licensed facilities. The 20.2002 exemption process is not transparent and it is cumbersome (see Chapter 3 and 4 for more discussions on this). Exemptions are granted on a case-by-case basis and implemented differently from state to state.[15]

In Ms. Edward's opinion, the 20.2002 exemption process and case-by-case approvals are subject to political whims, so that they might be affected by the release of a newspaper article or by an election. Adding a classification and set of requirements for the lowest activity of Class A would be more transparent and beneficial.

Figure 2-3 illustrates the potential economic impact of defining a new VLLW classification. The blue solid line represents the total expected LLW to be generated at U.S. NPPs through the year 2056, including generation of very low-activity waste. As current NPPs begin decommissioning, the volume of LLW waste generated will increase. The green solid line excludes the very low-activity portion of the waste that could potentially be diverted to RCRA facilities instead of LLW disposal facilities. The cost of disposing of this waste in RCRA facilities is significantly lower—EPRI estimates the total savings would be in the $6 billion range—than disposing of the waste in a LLW facility. The cost savings is the difference between dotted blue and green lines in the figure.

Low-Level Radioactive Waste

Mr. Shrum began his prepared remarks by commenting on the previous presentation. He agreed that the question raised by Ms. Edwards of how to best address the disposal of the expected large quantity of very low-activity waste from NPP decommissioning (see Figure 2-3) should be answered sooner than later, and also that the United States should have a more uniform standard for addressing very low-activity radioactive waste (see Chapter 3 for more discussion on VLLW and exempt or clearance waste).

Mr. Shrum noted that EnergySolutions (his employer) operates two

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Class A limits contained in Part 61, and for which the extensive controls in Part 61 are not needed to ensure protection of public health and safety and the environment. Thus, 10 CFR 20.2002 provides an alternative, safe, risk-informed disposal method for these materials, which are frequently called 'low-activity waste.' Although these materials could be disposed of in a licensed low-level radioactive waste facility, if a licensee chose to do so, disposal at another type of facility under 10 CFR 20.2002 may significantly reduce transportation distances (often on the order of one to two thousand miles), provide for more disposal options, and lower disposal costs, while still providing for protection of public health and safety and the environment. . . ." (See "Low-Level Waste Disposal Under 10 CFR 20.2002," accessed April 9, 2017, https://www.nrc.gov/waste/llw-disposal/10cfr20-2002-info.html.)

[15]The commercial LLW facilities are regulated by individual Agreement States (see Appendix D), which results in differences between the licensing requirements that they impose.

of the four commercial LLW disposal facilities in the United States: one in Clive, Utah, and another in Barnwell, South Carolina.

The LLW waste classification system in the United States (i.e., Class A, B, C, and GTCC) is based on activity and hazard.[16] The USNRC provides criteria for near-surface disposal of LLW:

- The external exposure to a member of the public resulting from release of the waste shall not exceed 25 millirem/year (mrem), effective dose equivalent (10 CFR Part 61.41);[17] and
- the dose to a person who inadvertently intrudes into the disposal site after loss of institutional control (100 years) shall not exceed a one-time commitment of 500 mrem or an annual dose of 100 mrem for the first 1,000 years after emplacement (10 CFR Part 61.42).

For Class A waste, the hazard is minimal after 100 years; for Class B waste, the hazard timeframe increases to 300 years; and for Class C waste, it is 500 years. Because of its higher hazard, Class C waste must be buried at least 5 meters below the surface and have an engineered barrier.[18]

EnergySolutions has received a wide variety of LLW streams at its disposal facilities including paper, rags, plastic, glassware, syringes, protective clothing, cardboard, packaging material, spent pharmaceuticals, water-treatment residues, contaminated ion exchange resins, filters, tools, irradiated metals from nuclear power plants, and animal carcasses. The animal carcasses have to be incinerated because the facilities cannot directly dispose of organic materials.

Mr. Shrum stated that the main challenge of LLW disposal in the United States is not technical. The main challenge is political. Prior to the enactment of the Low-Level Radioactive Waste Policy Act of 1980 (LLRWPA),[19]

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[16] See the USNRC classifications at "Part 61.55 Waste classification," accessed April 9, 2017, https://www.nrc.gov/reading-rm/doc-collections/cfr/part061/part061-0055.html.

[17] Note that 10 CFR Part 61.42 does not list dose limits for an inadvertent intruder. However, the concentrations of radionuclides established in Part 61 Tables 1 and 2 assumed a (maximum) dose of 5 millisievert/year (500 mrem/year). For more information see "Technical Basis for Proposed Rule to Amend 10 CFR Part 61 to Specify Requirements for the Disposal of Unique Waste Streams, including Large Quantities of Depleted Urainum (FSME-10-XXXX)," accessed April 9, 2017, https://www.nrc.gov/docs/ML1110/ML111040419.pdf. Note that the average annual exposure for a member of the public in the United States is 620 mrem/yr, including medical procedures (see "NCRP Report No. 160, Ionizing Radiation Exposure of the Population of the United States," accessed March 27, 2017, available for purchase at http://ncrponline.org/publications/reports/ncrp-report-160/).

[18] Mr. Shrum noted here that transuranic (TRU) waste is an exception and can be considered LLW in some instances (see LLW definition and notes in Box D-1). During the discussion session, a participant asked for further clarification on Mr. Shrum's statement about TRU waste.

[19] See Box D-2 in Appendix D for a description of the LLRWPA, its amendment in 1985, and other laws related to LLW regulation.

FIGURE 2-4 Locations of the four U.S. commercial LLW disposal facilities; compare the number and distribution to Canadian facilities shown in Figure 2-1.
SOURCE: U.S. Nuclear Regulatory Commission.

there were three operating disposal facilities in the United States: Beatty, Nevada; Barnwell, South Carolina; and Hanford, Washington. The governors of these states testified to Congress that they should not bear the burden of LLW disposal for the whole nation. Congress agreed and established the LLRWPA.

The purpose of the LLRWPA was to distribute LLW disposal obligations across the United States by establishing a state compact system[20]—assuming that regional disposal would be the safest and most efficient and equitable means for managing LLW. The United States now has four operating disposal facilities for commercial LLW (see Figure 2-4 and Table D-1 in Appendix D):

- EnergySolutions LLW Disposal Facility, Barnwell, South Carolina, accepts Class A, B, and C waste;

[20]See Appendix D for further descriptions of Agreement States and the state compact system. Table D-1 lists the state compacts that are associated with each commercial LLW facility.

- EnergySolutions LLW Disposal Facility, Clive, Utah, accepts Class A and 11.e (2) waste;[21]
- WCS, Texas, accepts Class A, B, and C and 11.e (2) waste; and
- US Ecology, Inc., LLW Disposal Facility, Hanford Site, Washington, accepts Class A, B, and C waste.

Since the LLRWPA was enacted, the EnergySolutions LLW Disposal Facility in Clive and WCS in Texas have opened. Clive accepts Class A waste from all 50 states. Both WCS, Texas and the EnergySolutions, Clive facilities can accept DOE waste.

Mr. Shrum noted that when the LLRWPA was enacted, there was no analysis to determine whether there was enough LLW generation to support multiple state compact disposal facilities. Currently, all states have access to some disposal capacity, and waste does not have to be transported very far, which keeps transport risk low—Mr. Shrum stated that the transportation of LLW has a great safety record and is one of the safest aspects of the LLW disposal system.

2.3 DISCUSSION: CLASSIFICATION, CATEGORIES, AND CHARACTERISTICS OF LLW

The content of the discussion sessions is grouped by topic in these proceedings and may not appear in the same order as they occurred during the workshop. The main topics are highlighted in bold headings.

Very Low-Level and Clearance Waste in the United States

Several participants asked questions about the criteria for VLLW and clearance (or exempt) waste, referring to presentations by Mr. Garamszeghy and Ms. Edwards and comments by Mr. Shrum.

Participants asked for more details related to the cost savings of using a VLLW category for decommissioning. Specifically, Francis X. "Chip" Cameron, currently with CameronGray LLC and an ex-USNRC assistant general counsel, asked for an estimated cost difference to send the expected volume of very low-activity waste to a Class A versus RCRA site for the San Onofre NPP decommissioning. Ms. Edwards recalled the cost savings between disposals at a Class A versus a RCRA facility to be approximately a factor of 10. However, she also noted that waste disposal does not make up the majority of decommissioning costs. The main cost for decommissioning is labor (personnel). Gérald Ouzounian, international director at

[21] The Atomic Energy Act, Section 11.e, defines byproduct material "11.e (2)" refers to the tailings or waste produced by the processing of ore to extract uranium or thorium. See Box D-1 in Appendix D for more information.

ANDRA,[22] added that, in France, VLLW has been disposed of in a facility separate from LLW since 2003. The cost savings for disposal is between a factor of 15 and 18. Dr. Ouzounian also noted that the French are moving toward optimization of the full system costs as opposed to the separate costs for dismantling and disposing of the waste.

Scott Kirk, director of regulatory affairs for BWXT, asked Ms. Edwards whether the $6 billion in projected cost savings shown in Figure 2-3 represented the total number of plants that are planned for decommissioning over the timeframe represented in the figure. How was this cost savings calculated?

Ms. Edwards explained that the exact shape and height of the solid blue and green lines in Figure 2-3 could change if there are changes in the assumed scheduling of future NPP shutdowns. However, the area under each of the curves (i.e., the total volume of LLW generated from reactor decommissioning) will be more or less the same regardless of when the reactors are decommissioned. EPRI assumed that the cost of disposing of decommissioning wastes will be the same regardless of the exact timing of decommissioning. In summary, the cost estimate shown in Figure 2-3 represents the total number of reactors that are expected to be decommissioned over the timeframe represented in the figure.

Mr. Camper asked what criteria should be specified in a regulation that would replace the case-by-case exemption process described by Ms. Edwards for VLLW. Ms. Edwards responded by referencing two publicly available EPRI reports, as noted in her presentation. The report, *A Generic Technical Basis for Implementing a Very Low Level Waste Category for Disposal of Low Activity Radioactive Wastes* (EPRI, 2013), analyzed how the VLLW category is applied outside of and within the United States. A comparison between U.S. RCRA disposal facilities and VLLW disposal facilities that exist in France and Spain concluded that the sites compare favorably in terms of protectiveness.

Another EPRI report, *Basis for National and International Low Activity and Very Low Level Waste Disposal Classifications* (EPRI, 2012), proposed a definition for VLLW based on dose and isotopic limits from existing definitions of VLLW in countries in which that waste stream is recognized. The report also considered the characteristics of the waste in which the 20.2002 exemption process was used. Additionally, doses for intruder and other scenarios were developed to postulate criteria and limits. The resulting criteria are more conservative than what is used in other countries. Ms. Edwards noted that the reports were written to provide information to "start a conversation" about this new waste category.

Mr. Shrum noted that very low-activity waste disposal is one of

[22] ANDRA is the French acronym for National Radioactive Waste Management Agency.

EnergySolutions' top priorities. USNRC 10 CFR Part 61 addresses the disposal of LLW. In addition, there is a new ~500-page guidance document for 10 CFR Part 61. Mr. Shrum asked that a guidance document be created to add clarity to the reference of a "few millirem" in the 20.2002 exemption. This detail is important to the waste disposal industry because more very low-activity waste is disposed of under exemption than is disposed of at LLW facilities. Whether intentional or not, the current reality is that regulation of very low-activity waste is occurring through exemption. Additional guidance would help to clarify criteria, for example the "few millirem" reference above, for the industry and practitioners.

Mr. Camper recalled that several years ago, the USNRC's Office of General Counsel asked the USNRC staff to identify a basis for using a "few millirem" for a lower threshold. It was determined then that the USNRC staff was at liberty to use a higher number, but first it needed to alert the Commission. Mr. Camper agreed that it would be good to embody this criterion within regulation.

Both the USNRC and the Environmental Protection Agency (EPA) have spent considerable time and effort considering VLLW, as noted by several participants.[23] Mr. Camper asked John Greeves, USNRC retired, to provide further background on the USNRC's work on the clearance of very low-activity waste. Mr. Greeves noted that there is no lower threshold for LLW classification in the United States. The IAEA document, *Application of the Concepts of Exclusion, Exemption and Clearance Safety Guide* (referenced previously by Mr. Garamszeghy) has a clearance definition that the USNRC staff (including Mr. Greeves and others at the time) had supported but the USNRC never adopted. France has done an outstanding job of resolving this problem and provides an excellent case study on how to manage and dispose of VLLW. The USNRC staff completed an environmental impact statement (EIS) in 2005 to evaluate approaches for managing certain types of VLLW, but no action was taken. Mr. Greeves noted that the federal government and Congress have not focused on addressing this issue.

Mr. Camper recalled that the USNRC and EPA conferred in 2003 as EPA prepared an Advance Notice of Public Rulemaking (ANPR) on very low-activity waste. Mr. Camper asked Mr. Daniel Schultheisz, EPA, Office of Radiation, whether EPA considered developing criteria for VLLW at the time of the ANPR and, if so, how it aligned with what EPRI proposed in the generic technical basis report (EPRI, 2013). Mr. Schultheisz explained that EPA has been looking at the issue of VLLW for quite some time. The ANPR referenced above was released in 2003 and was, in fact, an iteration

[23] While not discussed during the workshop, it is worth noting that DOE utilizes a similar option (called the "authorized limits process") for waste with low concentrations of radioactivity through disposal at on-site Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) cells.

of previous work. EPA had originally considered a VLLW disposal option when it considered ways to make it easier for generators to dispose of mixed waste at RCRA facilities. This was broadened in the early 2000s to include working with the USNRC staff—Mr. Greeves in particular offered his staff to provide assistance.

EPA's approach is conceptually similar to what is proposed in the EPRI report (EPRI, 2013). The approach in the rulemakings before the ANPR was to establish specific concentration limits on radionuclides based on certain exposure scenarios. The limits were calibrated to particular dose levels and could be adjusted, allowing states the flexibility to implement as they saw appropriate. The states would not be required to adopt the dose levels.

The EPA received many public comments after the ANPR was released. However, at the same time, EPA staff were significantly distracted by the Yucca Mountain rulemakings. Mr. Schultheisz recalled that there was not significant support within the EPA at the time for a rulemaking on VLLW. Mr. Schultheisz noted that the EPA has continued to perform some modeling of different exposure scenarios—perhaps similar to what EPRI has done. The results are in a draft report, which has not yet been released.

The EPA is considering the application of the VLLW concept to wastes created by a radiological incident, such as a dirty bomb, or a nuclear accident such as occurred at Fukushima and Chernobyl. The EPA is establishing a planning process whereby clearance or VLLW designations could be implemented (see later discussion of this waste type in Chapter 3).

Kevin Crowley, director of the Nuclear and Radiation Studies Board at the National Academies, asked Mr. Garamszeghy whether the Canadian public had accepted the idea of clearance waste and whether there has been a difference in the ease or cost of disposing of this waste. Mr. Garamszeghy responded that in terms of public acceptance, certain members of the public are ideologically opposed. Regardless, clearance of the waste is allowed under regulation. He also noted that allowing for cleared waste has reduced the volumes of radioactive waste that have to be managed. All major nuclear waste producers, such as NPPs and research facilities, have implemented a "likely clean" program. The program is based on the separate collection and monitoring of waste, which, for operational reasons such as the location in the plant of its generation, is considered "likely clean." Those wastes are bulk collected and monitored. They can then be released for conventional recycle or disposal, depending on the waste type. In a number of cases, this resulted in a reduction of more than 50 percent in the amount of waste that has to be treated as radioactive waste.

The "likely clean" program has been in practice for more than 15 years and is very cost-effective. Most of the waste that gets diverted in this fashion is nonradioactive. The release criterion is basically background activity.

Background activity is a very conservative limit, so the waste is essentially clean.

New Rules in Averaging and Reduction in Class B and C Wastes

Ms. Edwards was asked by Diane D'Arrigo, the radioactive waste project director of the Nuclear Information and Research Service, whether her estimate or projection of future volumes of Class B and C wastes being reduced to zero was because of new calculations, physical mixing, or both. Ms. Edwards responded that she suspects that volumes of Class B and C wastes will approach zero due to the updated method for concentration averaging. Not all LLW containers or packages contain homogenous mixtures of waste. Some waste packages have "hot spots"[24] created by waste components that cannot be evenly distributed throughout the package such as filters or irradiated metals. In this case, a calculation determines the allowable activity level for these components of the waste. The term "concentration averaging" refers to this calculation.

The 1995 USNRC guidance on concentration averaging was intended to limit the concentrations of specific radionuclides within a given waste package as compared to the average activity of that package.[25] Updated guidance released in 2015 allows the concentration of the hot spot to be compared to the waste classification limit instead of the average concentration of the package.[26]

Ms. Edwards further explained that the important quantity for waste disposal is the total activity that goes into a single package. If a package meets the averaging constraints described above, then the higher activity from the hot spot is averaged with the other constituents over the total volume. This is the reason for Ms. Edwards' prediction that nearly all Class B and C waste from the utilities will be packaged as Class A waste in the future.

[24]The USNRC defines a hot spot as (USNRC, 2015b, p. 11) "a portion of the overall waste volume whose radionuclide concentrations are above the class limit for the entire container [or package]."

[25]See 10 CFR Part 61.55, Table 2 for the list of radionuclides and their concentration limits. For the text of the 1995 guidance, see "Issuance of Final Branch Technical Position on Concentration Averaging and Encapsulation, Revisions in Part to Waste Classification Technical Position," accessed April 9, 2017, https://www.nrc.gov/docs/ML0336/ML033630732.pdf.

[26]For the new "factor of 10" rule: the concentration of each radionuclide of concern in each item [or waste package] should be less than 10 times the classification limit for that radionuclide.

Waste Classification of LLW Containing TRU Nuclides

Dr. Crowley asked Mr. Shrum to clarify a comment made during his presentation on how TRU waste might be considered LLW. Mr. Shrum responded that, by definition, TRU waste is not LLW; nevertheless, 10 CFR 61.55 allows for near-surface disposal for waste containing TRU nuclides based on its characteristics. Dr. Crowley suggested that disposal of TRU as LLW might not be a problem because it is apparently allowed by regulation.

Mr. Camper noted two concerns with disposal of TRU as LLW: The first is that TRU waste is not included in the definition of LLW in 10 CFR Part 61 so it is disconnected from the LLRWPA Amendment. The second and larger concern is that Table 1 in 10 CFR 61.55 states that the Class C limit allows up to 100 nanocuries per gram (nCi/g) for waste containing TRU nuclides but it does not explicitly define waste containing more than 100 nCi/g of TRU nuclides.[27] The problem is that some of the waste defined in the final EIS for GTCC[28] waste is non-defense TRU waste for which there is no disposal pathway at present. This is the problem that the Commission directed USNRC staff to address via rulemaking.

Legacy (Historic) Wastes

Jennifer Heimberg, rapporteur and National Academies staff, asked the panel how legacy wastes are handled in Canadian and U.S. regulations and whether they are disposed of at commercial LLW facilities. Mr. Garamszeghy noted that the legacy wastes can be a challenge to address. In Canada, these wastes are the result of a number of activities (research, mining, industrial) dating back to the early 1940s. Many legacy waste streams are not well characterized in terms of radionuclide content, physical forms, or volumes. They have been stored or disposed of in facili-

[27]The following documents provide history and further background on the TRU waste problem (USNRC, 2015a and 2015c): "SECY-15-0094: Historical and Current Issues Related to the Disposal of Greater-than-Class C Low-Level Radioactive Waste," accessed March 28, 2017, https://www.nrc.gov/docs/ML1516/ML15162A807.pdf and "SECY-15-0094, Enclosure 3: Statutory Language and Regulatory History of Commercial Transuranic Waste Disposal," March 28, 2017, https://www.nrc.gov/docs/ML1516/ML15162A828.pdf.

The USNRC makes the following statement (Footnote 4, p. 2, USNRC, 2015a): "TRU waste is explicitly excluded from the definition of LLRW [low-level radioactive waste]. However, the [US]NRC has determined that LLRW containing TRU nuclides meeting certain criteria may be suitable for disposal within a 10 CFR Part 61 disposal facility. See 10 CFR § 61.55(a)(3), Table 1."

[28]See "DOE: Greater-Than-Class C Low-Level Radioactive Waste Environmental Impact Statement (GTCC EIS) Documents," accessed March 1, 2017, http://www.gtcceis.anl.gov/documents/index.cfm#final.

ties that do not meet modern standards. Consequently, there are uncertainties in the characteristics, quantities, and locations of these wastes. The Canadian federal government is ultimately responsible for managing these wastes; the government has a number of programs in place to characterize and manage them. For example, Mr. Garamszeghy recalled from his presentation that there were ~2.1 million cubic meters of VLLW in Canada.[29] This is largely historic waste from contaminated soil, decommissioning of legacy facilities, and similar activities. There is a proposal by Canadian Nuclear Laboratories, a contractor that operates the government's nuclear facility near Chalk River, Ontario, to develop near-surface disposal facility at that site for disposal of Canada's legacy wastes. Most of Canada's legacy waste resides at that site.

Mr. Shrum responded that EnergySolutions receives legacy waste, mostly from DOE. This waste is often referred to as "look what we found" waste because of its unpredictable characteristics. Mr. Shrum noted that DOE has a different waste classification scheme than the one used by the USNRC. If DOE legacy waste is identified and planned for disposal at a commercial facility, DOE will typically use waste processors or brokers to first characterize the waste, confirm that it meets the facility's waste acceptance criteria, and that the waste meets the requirements in 10 CFR Part 61.55.

2.4 REGULATIONS, STANDARDS, ORDERS, AND GUIDANCE CRITERIA

Mr. Camper began the session by providing an overview of the U.S. LLW regulatory process. His remarks are summarized below. The regulatory process has a proven track record and has been shown to adequately protect health and safety. However, the process is complicated (a "regulatory mosaic"), may be difficult to understand or explain, and lacks exact alignment with other international regulatory frameworks. There is room for improvement.

A number of key pieces of legislation directly impact the management and disposal of LLW. These are identified and briefly described in Box 2-1 and in Appendix D.

Mr. Camper identified the key regulators of radioactive waste within the United States and stressed the key role that Agreement States play in regulating the four commercial LLW disposal facilities. The EPA develops standards applicable to LLW disposal. The USNRC has regulatory oversight of commercial radioactive waste in the United States under the

[29] This estimate uses the IAEA GSG-1 classification of VLLW; however, the waste is currently termed "LLW" by the waste owners.

BOX 2-1
Key Legislation for LLW

Atomic Energy Act (1954):
the original statute from which the USNRC derives its authority.

National Environmental Policy Act (1969):
describes the environmental analyses that are performed for licensing actions, including the licensing of LLW disposal facilities.

Transportation Safety Act (1974):
sets forth criteria for the transport of LLW for disposal.

Resources Conservation and Recovery Act (1976):
created the framework for the management of hazardous and non-hazardous solid wastes.

Low Level Radioactive Waste Policy Act (1980) and amendment (1985):
defined the compact system (see Mr. Shrum's presentation and Appendix D) and enables the states to dispose of their LLW.

Nuclear Waste Policy Act (1982) and Amendment (1987):
requires the USNRC to ensure that licensees providing for the disposal of LLW provide adequate financial arrangements to permit disposal site closure and reclamation of sites, structures, and equipment.

Comprehensive Environmental Response Compensation and Liability Act (1986):
contains standards that apply to hazardous waste facilities, also referred to as Superfund (see also the Resource Conservation Recovery Act [RCRA]).

Energy Policy Act of 2005:
extended authority of the USNRC as it pertains to discrete sources of NORM (naturally occurring radioactive material).[a]

Ronald Reagan Defense Authorization Act (2005):
addressed DOE's disposal of waste incidental to reprocessing for the Idaho National Laboratory and the Savannah River Site.

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[a]The EPAct of 2005 adds the following to the list of byproduct materials: "any discrete source of naturally occurring radioactive material, other than source material, that—(A) the [Nuclear Regulatory] Commission, in consultation with the Administrator of the Environmental Protection Agency, the Secretary of Energy, the Secretary of Homeland Security, and the head of any other appropriate Federal agency, determines would pose a threat similar to the threat posed by a discrete source of radium-226 to the public health and safety or the common defense and security; and (B) before, on, or after the date of enactment of this paragraph is extracted or converted after extraction for use in a commercial, medical, or research activity."

Atomic Energy Act. The DOE is self-regulating for the wastes it generates and stores. Mr. Camper noted that the Department of Transportation also has regulations for transporting LLW, but these regulations are enforced by the USNRC.

DOE regulates its radioactive wastes through two orders:[30]

- Order 458.1—*Radiation Protection of the Public and the Environment,* and
- Order 435.1—*Radioactive Waste Management*.

The key USNRC regulations are the following:

- 10 CFR Part 20—*Standards for Protection against Radiation*
- 10 CFR Part 61—*Licensing Requirements for Land Disposal of Radioactive Waste*
- 10 CFR Part 62—*Criteria and Procedures for Emergency Access to Non-Federal and Regional Low-Level Waste Disposal Facilities*

10 CFR Part 62 was created when there was no access to disposal for Class B and C wastes for 36 states. This provision has not been used to date.

Mr. Camper listed other entities that influence the regulatory process, including the Compact Commissions for the states, Conference of Radiation Control Program Directors, Inc. (CRCPD),[31] International Commission on Radiological Protection (ICRP),[32] Low-Level Radioactive Waste Forum, Inc.,[33] National Council on Radiation Protection and Measurements (NCRP),[34] and

[30]DOE Orders are described as a type of Directive: "Orders establish management objectives and requirements and assign responsibilities for DOE Federal employees consistent with policy and regulations. Requirements must be unique to DOE and must avoid duplicating information from other directives or any existing legal source." These orders and DOE policies provide for site-specific performance assessments and site-specific waste acceptance criteria to establish an envelope of acceptable LLW forms and packages between waste generators and waste disposal sites. See: "DOE: DIRECTIVES HELP," accessed March 1, 2017, https://www.directives.doe.gov/directives-help.

[31]The mission of CRCPD is "to promote consistency in addressing and resolving radiation protection issues, to encourage high standards of quality in radiation protection programs, and to provide leadership in radiation safety and education." For more information, see "An Introduction to CRCPD," accessed March 1, 2017, http://www.crcpd.org/page/About.

[32]According to its website, ". . . the International Commission on Radiological Protection (ICRP) helps to prevent cancer and other diseases and effects associated with exposure to ionising radiation, and to protect the environment." For more information, see "About ICRP," accessed April 9, 2017, http://www.icrp.org/.

[33]The Low-Level Radioactive Waste Forum, Inc. is focused on helping the states and interstate compacts implement the requirements of the Low-Level Radioactive Waste Policy Amendments Act (see Box 2-1). For more information, see "About Us," accessed April 9, 2017, http://llwforum.org/about/.

[34]For more information, see "National Council on Radiation Protection and Measurements: About," (accessed April 9, 2017) http://ncrponline.org/about/.

Organization of Agreement States (OAS).[35] The ICRP and NCRP develop protection criteria that may be used in various statutes and/or guidance. The OAS assists the Agreement States and coordinates actions with the USNRC.

Mr. Camper provided further background on the Agreement States program. The program was established by the Atomic Energy Act (AEA), as amended. Section 274b of the Act allows the USNRC to relinquish portions of its regulatory authority to an Agreement State.[36] The state governor and the chairman of the USNRC must sign an agreement recognizing "the State shall have authority to regulate the materials covered by the agreement for the protection of the public health and safety from radiation hazards" (AEA, Section 274b). The USNRC conducts an integrated management performance evaluation program through inspections and licensing to regularly confirm that the Agreement States' programs are sufficient and compatible with federal regulations.

The states' role in LLW management and disposal have evolved in response to the LLRWPA (see Box 2-1) in three important aspects: first, each state must dispose of LLW generated within its borders, either individually or through compacts. Second, states may assume regulatory authority as discussed above. Third, states have the authority to regulate naturally occurring radioactive material (NORM) and technically enhanced naturally occurring radioactive material (TENORM). Regulatory authority for these materials was not specified in the AEC.

Mr. Camper noted that the United States is fortunate to have four LLW disposal facilities; many countries have not yet determined a long-term solution to storage and disposal of LLW. The fact that the IAEA has safety standards, disposal requirements, and a general safety guide was mentioned by Mr. Camper; these are discussed in further detail later in these proceedings.

Mr. Camper noted that the U.S. regulatory process for LLW relies on an integrated safety system approach, which has proven effective in protecting human health and the environment but is technically complex. The approach involves many considerations such as site selection, site design, facility closure, post-closure stabilization, and institutional controls.

Finally, Mr. Camper noted that these are interesting times for regulation of LLW in the United States. U.S. regulators are addressing complex waste streams that were not included in the original analyses in 1982 for 10 CFR Part 61, including some waste streams identified for discussion in this workshop such as depleted uranium (DU), GTCC, and commercial TRU wastes. USNRC staff have been asked by the Commission to consider

[35]The purpose of the OAS is to "provide a mechanism for these Agreement States to work with each other and with the United States Nuclear Regulatory Commission ([US]NRC) on regulatory issues associated with their respective agreements." For more information, see "About OAS," accessed April 9, 2017, http://www.agreementstates.org/page/about-oas.

[36]Note: Kentucky became the first Agreement State in 1962.

changes to regulations for some of these wastes. There will likely continue to be great stakeholder interest in these regulatory changes.

In introducing the session, Mr. Camper explained that the three invited speakers were asked to address the following questions in their presentations:

- What are the health, environmental safety, and security bases that led to the generally applicable standards and regulations in your line of work?
- What are the strengths and weaknesses of the respective approaches?

Andrew Orrell, section head of waste management and environmental safety, IAEA, provided an international regulatory perspective; Thomas Magette, managing director of PricewaterhouseCoopers, provided an industry perspective; and Mark Yeager, environmental health manager for South Carolina Department of Health and Environmental Control (DHEC), provided perspectives from an Agreement State regulator.

LLW Management and the IAEA, Regulations, Standards, Orders, and Guidance

Mr. Orrell addressed the following topics in his presentation: IAEA statute (authority), IAEA safety standards, supporting guidance, and the Joint Convention. The statute that created the IAEA specifically authorizes it to develop and promote the application of safety standards for the benefit of its member states. These standards are intended to be an expression of international consensus about what constitutes a high-level of safety.[37] However, the IAEA is not a regulator, so its safety standards are not legally binding. They are used in different ways in different countries because the regulation and enforcement of safety is the sole responsibility of each IAEA member state.

The IAEA has produced more than 200 documents related to safety standards that cover nuclear technologies and the full nuclear fuel cycle. The wheel diagram in Figure 2-5 shows all of the current safety standards.[38] The overarching safety fundamentals are the highest in the hierarchy (a single document at the center of the wheel in blue), followed by the safety requirements (seven documents in red) and the more detailed safety guides (more numerous documents shown in green).

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[37]The IAEA currently has 168 member states. The statute governing its operation can be found at: “The Statute of the IAEA,” accessed April 9, 2017, https://www.iaea.org/about/statute.

[38]For a list of all of the safety standards shown in Figure 1-5, see: “Safety Standards applicable to all facilities and activities,” accessed April 9, 2017, http://www-ns.iaea.org/standards/documents/general.asp.

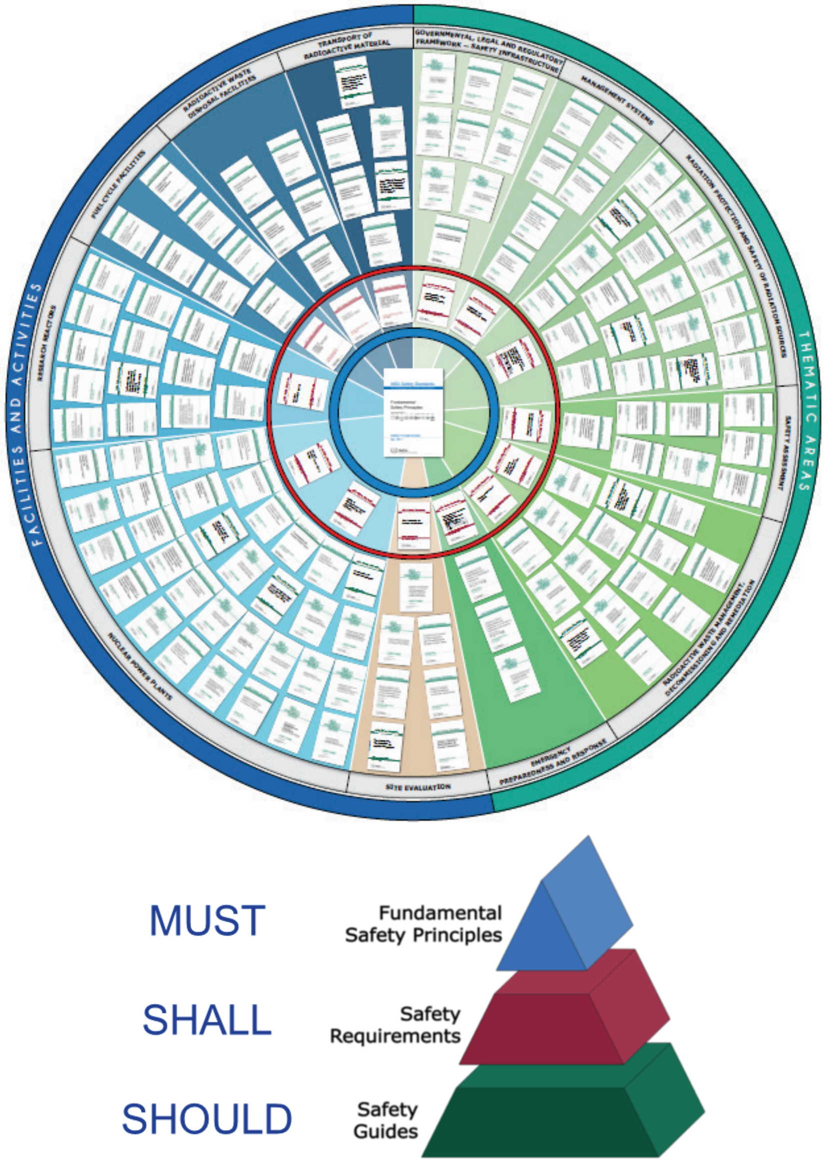

FIGURE 2-5 Safety standards developed by the IAEA. Fundamental Safety Principles are the highest level in the hierarchy (top blue triangle and the blue center of the wheel). Safety requirements are the middle level of the hierarchy (in red). Safety guides are the bottom level of the hierarchy (in green and in the outer rim of the wheel). The small script in the figure does not allow one to read the titles of each document; rather, the figure is meant to illustrate the number and hierarchy of the standards.
SOURCE: Courtesy of the International Atomic Energy Agency.

The safety fundamentals lay out the fundamental safety objective: to protect people and the environment from the potential harm of radioactivity.[39] "People" refers to both the worker and the public.

The safety fundamentals lay out 10 safety principles of protection and safety and provide the basis for the underlying safety requirements:

1. Responsibility for safety
2. Role of government
3. Leadership and management for safety
4. Justification of facilities and activities
5. Optimization of protection
6. Limitation of risks to individuals
7. Protection of present and future generations
8. Prevention of accidents
9. Emergency preparedness and response
10. Protective actions to reduce existing or unregulated radiation risks

These principles are constructed to use "must" statements and are at least notionally binding on member states.

Safety requirements elaborate on the fundamental safety objective and the 10 safety principles. Key safety requirement documents include one each for predisposal and disposal of radioactive waste.[40] The guides are meant to be concise and indicate "what," "by whom," and "when" actions should be taken and "why" the requirement exists. The safety requirements are constructed to use "shall" statements and are also at least notionally binding on member states.

At the bottom of the hierarchy in Figure 2-5 are the safety guides—captured in general and specific guides that provide recommendations on "how" to comply with the upper-tier requirements. The guides cite present international good practices and increasingly reflect best practices. The safety guides are constructed to use "should" statements.

Mr. Orrell's presentation included examples of a number of safety guides relevant to radioactive waste management, predisposal, storage, and disposal. He highlighted a few guides of particular relevance to the workshop: the classification of waste, management systems for predisposal and disposal frameworks, guidance on constructing a safety case and safety

[39]See "The IAEA Safety Standard: Fundamental Safety Principles, No. SF-1," accessed April 9, 2017, http://www-pub.iaea.org/MTCD/publications/PDF/Pub1273_web.pdf.

[40]"Predisposal" is a term used to describe the (IAEA, 2009b, p. 1) "management of radioactive waste from its generation up to disposal, including processing (pretreatment, treatment, and conditioning), storage and transport." For the general safety requirement guide on predisposal of radioactive waste (GSR Part 5), see (IAEA, 2009b). For the specific safety requirement guide for disposal of radioactive waste, see (IAEA, 2011).

assessment (which are crucial to the demonstration of safety of the radioactive waste management), and several specific guides on predisposal and disposal in near-surface and deep-geologic settings.

In addition to the official safety standard series, the IAEA also publishes a large number of supporting documents; these documents elaborate on best practices and/or good international practices for implementing radioactive waste management and also capture the results of technical meetings, conference proceedings, and workshops. All publications are developed by representatives of member states to benefit from their breadth and depth of available expertise.

Mr. Orrell noted that the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management[41] is a legal instrument to the 75 contracting parties that obligates each to implement the principles contained in the IAEA safety standards.[42] The Joint Convention went into force in 2001. Many of the technical obligations in the Joint Convention have strong parallels to the subjects covered in the safety standard series.

Mr. Orrell also noted that the IAEA safety standards represent six decades of experience and expertise, and they provide international consensus on what is needed to achieve a high level of safety. He noted that there is a common commitment to the protection of people and the environment regardless of the scale of a member state's activities. He presented a photograph of a VLLW disposal cell for a small European country with a very small nuclear footprint (Figure 2-6). This one cell has a capacity for 30,000 cubic meters of VLLW. The cleanup from the Fukushima Daiichi accident has generated more than 10 million cubic meters of contaminated soils to date—which would fill roughly 400 of the disposal cells in the small European country.

Complications in the Process of Creating and Revising Regulations

Mr. Magette noted, as have others, that the USNRC is in the midst of updating 10 CFR Part 61. He reviewed the complications of revising and creating regulations to account for challenging LLW streams such as DU and TRU. The update, originally proposed as a "tweak" 8 years ago, was needed to account for the large quantities of DU waste expected to be sent to commercial disposal facilities. Mr. Magette suggested that the level of

[41]For more information, see "IAEA: Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management," accessed March 1, 2017, http://www-ns.iaea.org/conventions/waste-jointconvention.asp.

[42]The number of parties and signatories was last updated on March 3, 2017; see "Joint Convention status," accessed April 27, 2017, http://www.iaea.org/Publications/Documents/Conventions/jointconv_status.pdf.

FIGURE 2-6 An operational disposal site for very low-level waste (VLLW). This facility is one cell (approximately 150 meters in length, 40 meters in width with a capacity of 30,000 cubic meters). Note the small gray cubes at back of facility; each is one cubic meter of VLLW.
SOURCE: Courtesy of Andrew Orrell.

effort required to modify the regulations thus far has been disproportionate to the risk posed by DU waste.

He identified several reasons for his opinion. The first is that Agreement States have been given the authority to regulate LLW. If one were to redesign a system to regulate LLW with our current understanding of the variety and volumes of LLW streams, it is hard to imagine a system that would allow individual states to regulate LLW because there is no distinction in health and safety benefit as one crosses state lines. Mr. Magette explained that the transition of authority from the USNRC to the states was not as clear as suggested previously by Mr. Camper. For example, updating the compatibility category tables,[43] which help to define how states may

[43] Compatibility category tables define how states may interpret USNRC regulations—these should not be confused with the tables used to classify wastes as Class A, B, C or GTCC.

interpret USNRC regulations, has further complicated the recent update process.

Several of the USNRC Commissioners recently and informally asked Mr. Magette if he thought a uniform regulatory regime would be a disincentive for states to develop disposal sites. He responded that it would have little impact because the debates about the development of such facilities are rarely focused on regulations. He also noted that changes to regulations are not a high-priority issue for most of the states because there are only four that host such facilities. Finally, disposal facilities are sited and developed by private entities, not by states and compacts.

Mr. Magette argued that it is necessary to adjust the LLW regulatory system to the situation in which we find ourselves. A small change to the regulations was proposed 8 years ago to address the increasing quantities of DU. The effort expanded to consider the revision of the classification tables in 10 CFR Part 61.55 for DU, GTCC, and TRU—a much more difficult effort than making a small change to the tables to account for DU only. One might reasonably ask whether the process has become overly complicated relative to the risks or hazards posed by the disposal of these materials. The LLW disposal system works today, but it is not clear whether the updates will improve it.

Mr. Magette highlighted several specific waste streams for which the existing regulatory system has become overly complicated. The radioactive emissions from DU increase slowly over time due to a build-up of daughter products—reaching a maximum value in approximately 1 million years. This growth in emissions necessitated a review of the length of the current compliance period for disposal of DU. The USNRC staff proposed to the Commission a two-tiered compliance process: a compliance period of 1,000 years or 10,000 years, depending on whether a facility accepts long-lived waste. However, this proposed change would double the compliance period from 500 years for Class C waste and increase it by a factor of 10 for Class A waste. Mr. Magette pointed out that there is no good technical basis to support this increased regulatory compliance period for non-long-lived waste.

The other complication is the period of institutional control following the closure of the LLW disposal facility. The public debate with USNRC staff focused on institutional controls and whether it was reasonable to maintain such control beyond 100 years. Mr. Magette suggested that the discussion should have focused on acknowledging that the risk diminishes over time; an increased period of institutional control resulted in much lower risk at the end.

Agreement State Programs

Mr. Yeager reviewed the Agreement State programs, addressing the two questions posed at the start of this session. He noted that Texas, Utah, Washington, and South Carolina regulate the four commercial LLW disposal facilities in the United States. These are Agreement States, and each works within similar regulatory structures.

In general, the Agreement States adopt the requirements in these regulations in their state regulations. For example, South Carolina's radiation protection standards for LLW waste disposal are compatible with the USNRC's 10 CFR Part 20, *Standards for Protection against Radiation*. South Carolina's radiation protection requirements are set forth in *Regulation 61-63, Title A, Part III* (State of South Carolina, 2014). The regulations apply to the public, workers, and vendors who provide services at the sites, and they establish occupational dose limits, surveys and monitoring, precautionary procedures, and required records and reports.

The conditions and operational procedures that commercial LLW licensees implement to comply with state and federal regulations are incorporated within their respective radioactive material licenses. In South Carolina, DHEC conducts radiological surveys and the physical inspection of the Barnwell Disposal Facility (BDF) biannually to document that license conditions and corresponding procedures are compliant. The BDF's LLW receipt and disposal operations are inspected weekly, as needed. Weekly inspections are conducted of general site, active disposal trench conditions, and enhanced trench cap conditions resulting from preliminary site closure activities. The review of submittals for new disposal trench construction and on-site inspection of this activity is also conducted by department technical staff.

Mr. Yeager pointed to 10 CFR 61, *Licensing Requirements for Land Disposal of Radioactive Waste*, which are implemented in South Carolina's *Regulation 61-63, Part VII*. As was previously mentioned, Part 61 has recently been revised. As a result, the sited Agreement States will need a guidance document to help implement the changes—hopefully to be released with the updated Part 61. Mr. Yeager agreed with previous comments about the need to account for the costs of the changes. DHEC has not yet determined how the implementation of the changes to Part 61 will affect its program.

The final rule for Part 61 includes the following change (highlighted in the previous presentation by Mr. Magette): the existing technical analysis for protection to the general public will either have a 1,000-year or a 10,000-year compliance period, depending on the quantities of long-lived radionuclides that are planned for disposal or have already been disposed of. The technical analysis should include a new safety case analysis to identify defense in-depth protections and to describe the capabilities of the disposal system. Therefore, the Agreement States will have to provide a new technical analysis for the protection of inadvertent intruders that includes the revised compliance period and corresponding dose limit. In addition, the Agreement States will have to perform a post-10,000-year performance year analysis. This will add a new requirement to update the technical analysis at the time of site closure.

The USNRC *Branch Technical Position on Concentration Averaging and Encapsulation* (BTP) has been an essential tool in assessing proper waste classification, packaging, and disposal trench selection. The recent update of the BTP has affected the volume of LLW received at the BDF by allowing the blending down of Class B and Class C to higher concentrations of Class A. It is also important to mention that each commercial LLW disposal facility has established Waste Acceptance Criteria which both allows and restricts certain waste forms. Examples include radium, DU, and mixed waste.

One of the questions posed to the presenters was related to physical security. Mr. Yeager noted that South Carolina regulations follow the USNRC's 10 CFR Part 37, the *Physical Protection of Category 1 and Category 2 Quantities of Radioactive Material*. The licensee and DHEC determined that some shipments of Class B and C waste, such as irradiated hardware, require security during staging for disposal at the EnergySolutions BDF site. As a result, DHEC worked with a licensee to implement this protection so that it met the Part 37 requirements. Mr. Yeager concluded that EnergySolutions performed well in this respect.

Finally, with regard to regulations related to transportation, South Carolina implements and enforces the provisions of 49 CFR Part 173, *Subpart I for Class 7 (Radioactive) Materials*, and also the applicable provisions of 10 CFR Part 20. All incoming LLW shipments are all inspected to assure that communication requirements and the conveyance meets physical and radiological regulatory standards; the shipment manifest and waste description are reviewed to ensure compliance with waste acceptance criteria; and the packaging is adequate.

With regard to packaging, Mr. Yeager noted that DHEC has been delegated authority to conduct engineering reviews of proposed High-Integrity Containers utilized to assure adequate LLW containment (primarily for the disposal of dewatered ion-exchange resin) for a minimum of a 300-year disposal lifetime. Upon conclusion of construction and mandated testing, DHEC is authorized to issue Certificates of Compliance.

Mr. Yeager noted that one strength of the Agreement States is the opportunity for collaboration during periodic reviews conducted through the USNRC's Integrated Materials Performance Evaluation Program (IMPEP). Each IMPEP team includes an Agreement State member. The oversight by another regulatory program is usually beneficial for both Agreement State programs.

An important challenge faced by Agreement State programs is providing technical assistance to other regulatory programs that find themselves with issues involving the disposition of various solid wastes containing or contaminated with radioactive constituents. Examples of these wastes include, but are not limited to, discrete radium sources (mostly of military origin), radium residuals resulting from water or mineral processing, and tritium resulting from improper disposal of generally licensed devices in solid waste landfills. South Carolina is the home of multiple military installations. As a result, DHEC receives many calls from scrap metal dealers that have come across discrete sources of radium and some byproduct material from improperly disposed of licensed sources. Most dealers are small businesses and do not have the financial resources to properly dispose of these disused or orphan sources. Some sources containing byproduct material can be traced back to the licensee. Fortunately, programs such as DOE's Source Collection and Threat Reduction (SCATR) Program allow for disposal of these sources at minimal or no cost to the generator.

Radium in drinking water and the residuals from ion exchange and filter media present additional disposal challenges. Water providers who are not accustomed or experienced under a regulatory regime have difficulty dealing with the required physical protections for their workers. Also, the water providers are not accustomed to the extreme expense of disposing of radium-contaminated filter media. DHEC has issued Reg. 61-63, Part IX, *Licensing of Naturally Occurring Radioactive Material (NORM)*, to assist in the regulatory oversight of this activity and the resulting radiological wastes.

Finally, it was noted that tritium, due to its elemental form, is an insidious environmental contaminant common in all LLW disposal sites and some solid waste landfills. One area of concern with LLW shallow-land burial at the BDF and other disposal facilities, including some solid waste facilities, is the presence of tritium in off-site environmental monitoring wells. One way the facility operator manages this issue is to restrict access by potential receptors at the release point. At the BDF, construction of enhanced trench cap covers has been very successful in mitigating the percolation of precipitation and the resulting transport of tritium through groundwater off-site.

2.5 DISCUSSION: REGULATIONS, STANDARDS, ORDERS, AND GUIDANCE CRITERIA

Several topics (highlighted in bold) were brought up during the Session 1b discussion. Questions, answers, and general comments pertaining to a specific topic are grouped below. As for the Session 1a discussion overview, this overview does not follow the chronological order of the discussion.

Likelihood of Significant Changes to the U.S. Regulatory System

The panelists were asked about the likelihod of large-scale changes to the U.S. regulatory framework for LLW. All three panelists agreed that large-scale changes were very unlikely. Mr. Magette noted that such changes were "extraordinarily unlikely," and he cited another example of the USNRC's approach to tweaking its regulations to address an evolving problem: the decommissioning rule for NPPs. The USNRC is considering the application of regulations originally written to ensure worker and public health and safety during NPP operations to their decommissioning. He also recalled the failed effort to develop regulations for material below regulatory concern (i.e., exempt or cleared material) originally requested by Congress in the LLRWPA as amended in 1985.

Mr. Orrell provided perspectives both as an IAEA employee and a U.S. citizen. He agrees that the LLW regulatory framework is "not very likely" to change substantially, certainly not in his lifetime. However, he noted that he has seen, both in the U.S. and other nations' regulatory systems, regulatory creep over time. Regulations get more complicated with time as regulators adjust their regulations to address evolving problems, typically by adding to instead of removing standards. Eventually, the regulations become unwieldy, prompting a revolution instead of an evolution to change them. Whether the U.S. nuclear regulatory framework will undergo a revolution is difficult to predict, but other industries such as banking and airlines have gone through punctuated efforts to revise, wholesale, their regulatory frameworks.

Mr. Yeager added another example from his time as chairperson of the Committee on Radioactive Waste Management of the CRCPD. Mr. Yeager described an overly optimistic but failed attempt, at his first meeting as the chair, to obtain consensus on a uniform approach by the states and federal agencies. But he also cited a successful multi-agency effort that created a unified approach to radiological characterization as a reason to be hopeful for a similar effort in LLW management. The EPA's *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM)[44] was a collaborative effort by the EPA, USNRC, DOE, and the Department of Defense.

Another is for LLW disposal organizations responsible for regulatory oversight to consider oversight for each other. For example, the four commercial LLW disposal facilities in the United States are currently regulated by Agreement States. Each respective regulatory program is subject to peri-

[44] *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM) "provides detailed guidance on how to demonstrate that a site is in compliance with a radiation dose- or risk-based regulation." More information can be found at: "EPA: Radiation Protection: Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)," https://www.epa.gov/radiation/multi-agency-radiation-survey-and-site-investigation-manual-marssim, accessed March 1, 2017.

odic review by the USNRC to assure compatibility with applicable federal regulations. The IMPEP inspection team is comprised of USNRC inspectors and an Agreement State inspector. DOE, as a self-regulating agency, might benefit from an assessment of its LLW disposal regime by other regulatory entities.

Consensus on a unified approach to LLW disposal across Agreement States and federal jurisdictions is also needed, noted Mr. Yeager. Such a consensus could encourage buy-in from stakeholders and the public and possibly reduce disposal costs. Currently, there are several federal and state regulatory regimes; it can sometimes be frustrating for a LLW (or LLW of very low activity) generator to move from one to another. In South Carolina, for example, the EnergySolutions' BDF is a commercial LLW site regulated by the South Carolina DHEC; RCRA facilities in the state that contain mixed waste are regulated by the EPA; Savannah River is regulated by DOE; but the Mixed Oxide (MOX) Fuel Fabrication Plant at Savannah River is regulated by the both the USNRC and DOE.

Mr. Magette further commented that site-specific regulations are based in part on performance assessments because each site is different. This makes uniform regulations across Agreement States more difficult to develop.

Containment Approach to Addressing the Isolation Period

Ms. Edwards noted that although a substantial revision of current U.S. LLW regulations is unlikely, workshop attendees might consider approaches that extend beyond regulatory changes. In the spirit of the workshop, Ms. Edwards presented such an approach and asked for participants' perspectives.

From a strictly technical viewpoint, LLW poses a hazard with a finite lifetime. It is a fairly straightforward calculation to determine the lifetime of the hazard of the LLW inventory of any disposal site. Ms. Edwards suggested that if society is willing to impose institutional controls for the duration of the LLW hazard, there would be no need to consider exposure to the waste after that period (i.e., intrusion scenarios)—similar to Mr. Magette's comments that an increased institutional control period resulted in lower risk at the end.

The development of intrusion scenarios leads to disagreements that are difficult to resolve, primarily because one must hypothesize about the characteristics of intruder scenario, for example when and how the intrusion occurs and the characteristics of intruder exposures. There are differing viewpoints on what intruder scenarios are "reasonable" to consider; for example, how should one estimate the behavior of an intruder who lives 10,000 years in the future, and how does one determine whether the intrusion would have significant health effects given likely future medical advances? It is difficult to defend a dose analysis for an intruder scenario given these future uncertainties. If LLW is isolated for the duration of its hazard, there would be no reason to consider intruder scenarios. Ms. Edwards acknowledged that there may be cases where longer-term institutional controls are not workable and suggested that a different set of regulations could be developed for those cases.

Mr. Orrell offered a technical perspective based on his experiences in performing and managing many of the safety and performance assessments for the Waste Isolation Pilot Plant (WIPP) and Yucca Mountain. In these analyses, it was assumed that all repositories, near-surface or otherwise, fail when there is an intrusion. Intrusion scenarios are informative in and of themselves to understand the consequences of such failures. Other countries use the results of intrusion scenarios to inform their regulatory processes. In Mr. Orrell's opinion, the intruder scenario serves as a pass/fail element of the U.S. regulatory system rather than as an information-input to the system.

Mr. Orrell agreed that, unless there is a reasonable argument for increasing the characterization of risk or adding to public confidence, extending the isolation period may not make a lot of difference. Mr. Orrell noted it would be straightforward to recalculate an isolation period from 500 to 1,000 years. In practice, however, the uncertainty of the result would need to be reduced by an order of magnitude (or two) to significantly improve the characterization of risk for increasing the isolation period from 500 to 1,000 years.

Mr. Orrell also stressed the importance of the terminology being used in Ms. Edwards' question. For example, WIPP has a containment standard, whereas other repositories have dose standards. There is an assumption that most repositories will have a release over some (long) time period, so a containment standard may drive one to particular disposition solutions that may not always be readily available or achievable.

"Regulatory Morass"

Paul Black, chief executive officer of Neptune and Company, Inc., provided a summary of his thoughts from the session. He recalled Mr. Camper's characterization of the complex framework as a "regulatory mosaic" and suggested another term which he believes is more accurate: a "regulatory morass." Dr. Black highlighted several examples to support this opinion including containment requirements, the compliance period for DU, and overly complicated LLW regulations (Black et al., 2014). His concern is that the complexity and associated costs with disposal of LLW has an upstream effect on the nuclear industry.

He noted that there remains some question on the appropriate regulation for small amounts of DOE TRU waste that may be present in the disposal sites at NNSS and Los Alamos National Laboratory (LANL). There is a question of whether the EPA's containment requirements of 40 CFR 191 (Subpart B Section 191.13) apply or whether other regulations would be more appropriate. Dr. Black explained that 40 CFR 191 was written for deep geologic repositories which allows a small amount of the inventory to escape while still meeting regulatory requirements. Dr. Black argued that containment regulations are ill-suited for the level of risk posed by DOE's TRU waste in this example. The EPA and DOE have not yet determined which regulations apply, so no decision can be made.

Another example is the compliance period for DU, discussed earlier. The performance assessments must meet a peak dose—or peak activity—requirement. Peak activity for DU is 2.1 million years. Compare this to the disposal of uranium mill tailings for which the compliance period is shorter due to the use of different approaches for inadvertent intrusion. Mill tailings waste emits significant radiation from radon, but it will take 100,000 years or more for radon to build up in DU. Additionally, oil and gas producers may dispose of NORM and TENORM waste outside of the radioactive waste regulatory regime.[45]

Long compliance periods and other requirements add to the cost of radioactive waste disposal, which in turn can impact nuclear energy generation and nuclear medicine use. Dr. Black judges that overly conservative radioactive waste regulations are having a severe impact on the nuclear industry.

[45]National Research Council (2006b) also cites this example.

3

Successful Disposition Case Studies

Rebecca Robbins, planning committee member and predisposal unit head at the International Atomic Energy Agency (IAEA), moderated this session, which used case studies to highlight examples of successful low-level waste (LLW) management and disposal within current regulatory frameworks. The case studies presented situations in which previously challenging LLW streams[1] were successfully managed and disposed of. The first two presentations in this session provided case studies from the United States; the next two presentations focused on case studies from outside the United States. A discussion was held after all of these case studies had been presented.

The comments from the moderators, the panelists, and other workshop participants are their own. They do not necessarily represent official views of their employers, governments, or other organizations that may be mentioned in the presentations or discussions.

Dr. Robbins began the session by requesting the workshop participants, as they listened to each case study, to identify the "key characteristics" that contributed to its success. Key characteristics include the practices, activities, attitudes, and actions with respect to the case studies and associated regulatory frameworks.

Melanie Pearson Hurley, headquarters liaison in the Office of Field Operations within the Department of Energy (DOE), presented a DOE case study. Greg Lovato, deputy administrator at the Nevada Division of

[1] "Challenging LLW streams" are defined as LLW streams that have potentially non-optimal or unclear disposition pathways due to their origin or content and incompatibility with existing standards, orders, or regulations.

Environmental Protection (NDEP), provided examples of key characteristics for successful disposition from the perspective of a state regulator. For international case studies, Miklos (Mike) Garamszeghy, design authority and manager of technology assessment and planning for the Canadian Nuclear Waste Management Organization, provided two examples from Canada and Gérald Ouzounian, international director for the National Radioactive Waste Management Agency (ANDRA), provided a case study from France.

3.1 UNITED STATES CASE STUDIES

Case Study 1: Separations Process Research Unit Tank Waste Sludge

Mrs. Hurley presented the Separations Process Research Unit (SPRU) project as DOE's case study. In the early 1950s, research on plutonium and uranium separation techniques such as PUREX and REDOX[2] was performed at SPRU within the Knolls Atomic Power Laboratory (KAPL).[3] KAPL, now an active naval nuclear laboratory, is located near Schenectady, New York, adjacent to the Mohawk River. The inactive SPRU facilities occupy about 5 acres of land immediately adjacent to KAPL.

The research at SPRU was performed on a laboratory scale and supported larger operations at both the Hanford Site in Washington and the Savannah River Site in South Carolina. Radioactive liquid and sludge wastes resulting from the SPRU research were stored in seven tanks located on site. The SPRU project timeline was established by the demolition dates for the buildings in which the research was performed and the wastes were stored. There was a strict requirement that the sludge waste be removed and disposed of by spring 2014.

Figure 3-1 provides a cross-section and plan view of two facilities at SPRU. The top drawing is a cross-section of the G2 building, which housed the laboratories, hot cells, and separations processing and testing equipment, and the H2 building, which was used for liquid and solid waste processing. The G2 and H2 buildings are connected by an underground tunnel. The lower drawing in Figure 3-1 shows the plan view of buildings G2 and H2. The tank farm in the lower-right corner of the figure is the focus of this presentation.

The radioactive waste from chemical processing was stored in the H2 tank farm (seven underground concrete-enclosed stainless steel tanks). This waste included about 200 cubic feet (5.7 cubic meters) of sludge consisting

[2]REDOX (reduction oxidation) and PUREX (Plutonium and Uranium Recovery by Extraction) are processes for separating uranium and/or plutonium from irradiated fuel and targets.

[3]In the 1950s, KAPL was a government research laboratory created by the U.S. Atomic Energy Commission (a predecessor agency to DOE).

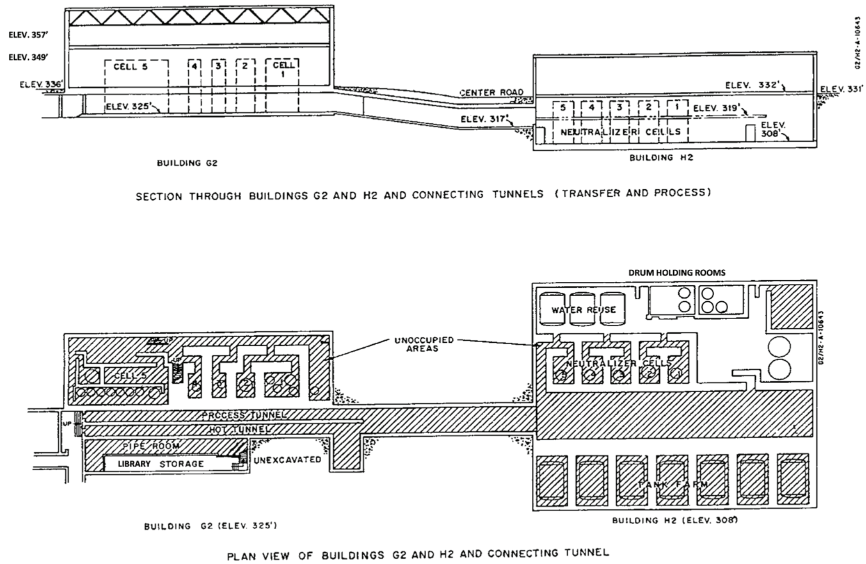

FIGURE 3-1 Schematic of SPRU facility showing cross-sections (top drawing) and plan views (bottom drawing) of Buildings G2 and H2.
SOURCE: Courtesy Jeff Selvey, AECOM.

of fine particulates and liquids containing fission products, mostly cesium and strontium, and long-lived transuranic (TRU) radionuclides, primarily plutonium-239. The sludge contained 36 curies of total radionuclides, including 2.5 to 6.5 curies of TRU radionuclides. The concentration of the long-lived TRU radionuclides in the final waste packages ranged from 11.5 to 65.5 nanocuries per gram (nCi/g).

The total mercury content of the sludge was more than 1 percent, and it contained high levels of lead, chromium, and cadmium. This led to an initial determination that the sludge may be a Resource Conservation and Recovery Act (RCRA) characteristic hazardous waste[4] for metals. This waste classification would have complicated the management of the sludge because the hazardous component would be regulated by the Environmental Protection Agency (EPA) in addition to DOE's regulation of the radioactive component. However, two toxicity characteristic leaching pro-

[4] "EPA: Defining Hazardous Waste: Listed, Characteristic and Mixed Radiological Wastes," accessed February 25, 2017, https://www.epa.gov/hw/defining-hazardous-waste-listed-characteristic-and-mixed-radiological-wastes#character.

cedures (TCLP)[5] confirmed that the hazardous component of the waste was only at 0-3 percent of regulatory levels, due to the low solubility of the metals in the sludge. Consequently, the sludge was determined to not contain hazardous waste and could more simply be managed under DOE orders.

DOE Order 435.1, *Radioactive Waste Management*, was used to guide decisions on disposing of the sludge from SPRU. The Order allows for the disposition of LLW in federal or commercial facilities. An exemption request must be approved by DOE headquarters for waste to be disposed of in a commercial disposal facility. Approval will be given if commercial disposal demonstrates compliance with regulations and waste acceptance criteria (WAC), is cost-effective, and is determined to be "in the best interests of the United States government."

There were two disposal options for the SPRU sludge: the Nevada Nuclear Security Site (NNSS), a DOE disposal site in Nevada, and Waste Control Specialists (WCS), a commercial disposal site in Texas. Both disposal options were explored, and WCS was selected, in part due to the compressed schedule[6] for completing cleanup of the SPRU tanks (spring 2014).

DOE worked closely with Texas regulators and WCS on establishing the waste profile[7] through the standard process described in the WCS Waste Acceptance Plan.[8] Texas regulators accepted DOE's policy that waste is not formally classified until all processing is completed and a stabilized waste form is produced. Mrs. Hurley identified this close collaboration as a "key characteristic" for successful disposition of the sludge.

The plan was to have the waste stabilized using a mixture of cement, fly ash, and slag that was then solidified in the final waste package for transportation and final disposal. The sludge solidification system at SPRU was designed and cold tested off site by the vendor and then installed in the H2 tank vault area. Cold-test operations were conducted on site prior to hot operations to ensure the system would perform as designed.

Figure 3-2 is a schematic of the H2 tank vault area and processing systems. Mrs. Hurley noted that there was an airborne release of radioac-

[5]TCLP testing determines the mobility of organic and inorganic chemical species within in liquid, solid, and multiphasic wastes. TCLP testing follows specific guidelines established by EPA.

[6]DOE had an existing contract with WCS, and WCS allowed for a shorter waste profile review time.

[7]"Waste profiles" are required documents for shipping and acceptance of waste. The waste generator must submit a waste profile of each waste package for approval by the disposal facility prior to shipment. The disposal facility reviews the waste profiles to confirm the waste is compliant with the WAC of the disposal site.

[8]"Application for License to Authorize Near Surface Disposal of Low-level Radioactive Waste, Appendix 5.2-1: Waste Acceptance Plan Revision 9," see Section 5.2: Waste Profile Approval, accessed February 25, 2017, http://www.wcstexas.com/wp-content/uploads/2016/01/Waste-Acceptance-Plan.pdf.

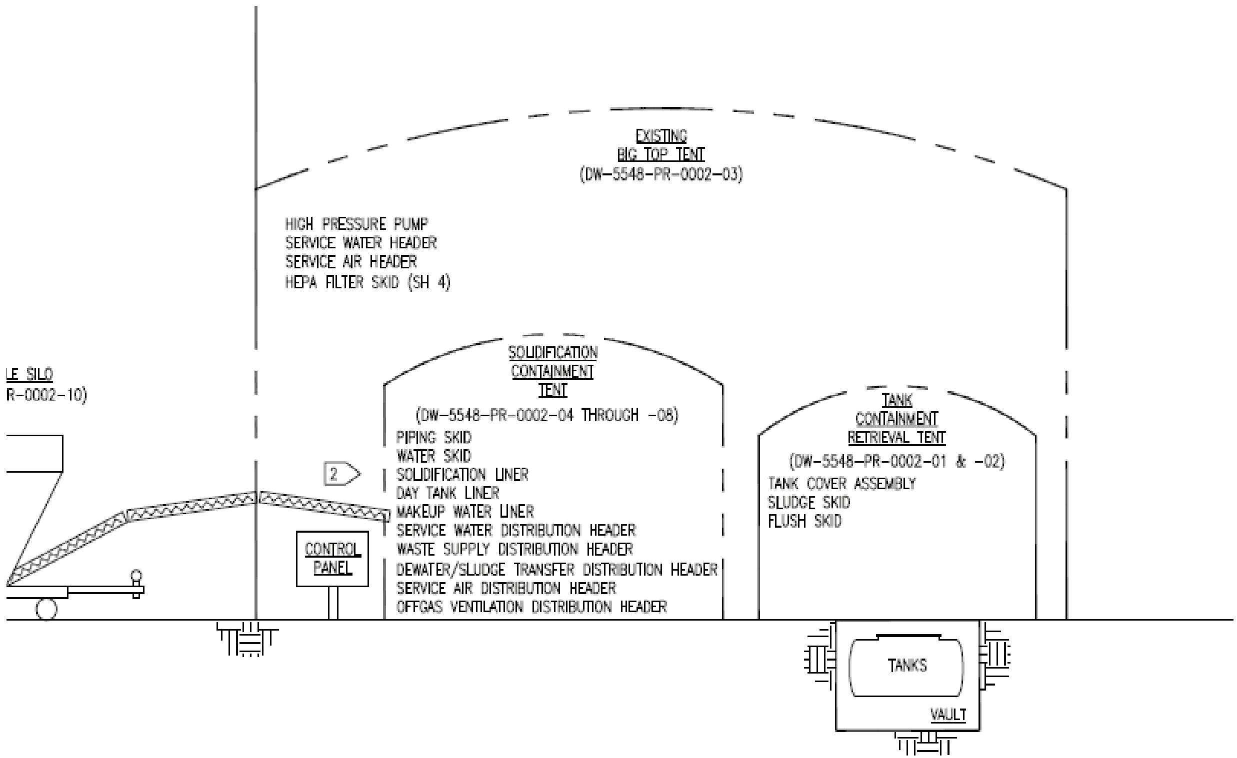

FIGURE 3-2 Schematic of the H2 tank vault area including SPRU processing contamination enclosures consisting of the outer enclosure (Area H2 Tent), the existing Big Top Tent, and two smaller tents for the sludge waste retrieval and processing (the Tank Containment Retrieval and Solidification Containment Tents).
SOURCE: Courtesy Jeff Selvey, AECOM.

tive material at SPRU in 2010. As a consequence of this event, the EPA required DOE to construct a tent enclosure over the H2 facility with portable ventilation units (contained in the outer tent, Area H2 Tent, shown in Figure 3-2). Underneath this larger tent is another tent (Existing Big Top Tent in Figure 3-2) that originally served as a weather enclosure over the tank farm. This weather-enclosure tent was retained when the larger enclosure was constructed to add another level of protection.

Within the Big Top Tent are two additional tents, the Tank Containment Retrieval and Solidification Containment Tents (see Figure 3-2). The sludge retrieval, mixing, processing, and characterization operations were carried out in these tents. Batches of sludge were retrieved from the 509E Tank,[9] mixed to suspend the solids in the waste, transferred to the final waste package, and then combined with cement, fly ash, and slag. The mixture was periodically checked by a penetration test to determine when it was solidified. If there was any remaining free water, additional cement mix was added.

The waste package was moved into a shielded temporary storage area set up in the G2 building (Figure 3-1).[10] The cement mixture curing times were long because the storage area was unheated. Once fully cured, the waste packages were shipped to WCS for disposal.

Sludge processing began on September 9, 2013, and the final shipments to WCS were completed on February 27, 2014.[11] Nearly 10,000 gallons of sludge were processed and solidified in 28 liners. The liners were shipped to WCS via trucks. (There were two liners per truckload and a total of 14 truck shipments.) This campaign removed the majority of the radionuclides from the SPRU site and allowed DOE's deactivation activities to continue in the H2 basement as scheduled.

While this case study highlights many successes, there were obstacles to overcome, including the following:

- Working within a decades-old facility with limited physical and onsite storage. There was no lay-down area where more than one liner could cure at the same time, and the temporary storage area in the G2 building allowed for 3 to 4 liners at a maximum.
- Retrieving sludge from the 509E Tank, including cleaning out solids near the bottom of the tank.
- Working with a waste stream (sludge) that is difficult to characterize and process. A continuous mixing system was used to keep

[9] In 2010, the sludge was consolidated into a single tank, the 509E tank, in preparation for waste processing and disposition.

[10] Mrs. Hurley noted that, at the same time the liners were temporarily stored there, deactivation activities were also taking place to prepare for demolition of the G2 building.

[11] The schedule accounted for the fact that concrete would not fully cure during the winter months (the SPRU tanks were covered by an unheated processing tent).

solids suspended in the waste so that the final waste form was homogenous.

- Performing the sludge processing work immediately adjacent (less than 25 feet or 7.6 meters) to a currently operating research and development laboratory and during deconstruction of the G2 building.
- Performing this work in a tent-type containment structure (Figure 3-2). Portable ventilation units and the HEPA[12] filters were used to ensure that safe working conditions were maintained.
- Addressing waste classification uncertainties. DOE performed historical research and additional evaluations to show that the sludge waste was not high-level waste and could be managed as LLW.

Several key management practices contributed to the success of this project:

- A dedicated and technically competent workforce that understood the mission objective and the importance of safety, including an excellent DOE federal project director.
- Frequent communications among the DOE participants, DOE staff from headquarters, NNSS, DOE's consolidated business center in Cincinnati, and KAPL, the adjacent research and development laboratory. Support from a "Senior Integrated Project Team" was also key to the success of the project.
- Cold testing of the treatment system at the vendor site and on site prior to operation enabled the right combination of nozzles, sluicing, and camera angles to confirm that the solids were removed from the 509E Tank.
- Early and frequent communication and engagement with the waste disposal experts from WCS.
- Coordination with the expertise throughout the DOE complex on packaging and transportation.

A participant asked Mrs. Hurley how DOE verified that solidification was adequate during cold testing. She responded that the cold testing was primarily to confirm the pump's ability to mix the solids and liquids and to confirm homogeneous mixing. Solidification was not tested or verified during cold testing; rather, a cement and fly ash "recipe" that was used successfully at other sites was used to solidify the SPRU sludge.

[12]HEPA is the acronym for high-efficiency particulate air.

Case Study 2: Low-Level Radioactive Waste Streams Reviewed for Disposal at the NNSS: Key Characteristics, Variation, and Management

Mr. Lovato's presentation included an overview of the waste disposal sites at the NNSS, the waste profile review process, key waste stream characteristics and their variation, and key management steps taken to address some of those different characteristics.

Mr. Lovato explained that NDEP was participating in the workshop because of a memorandum of understanding between the governor of Nevada and the secretary of DOE. One of the goals of the agreement is to hold a workshop to bring more transparency and predictability to DOE's waste disposal decisions. Mr. Lovato expressed thanks that the workshop was taking place. He noted the desire by Nevada citizens for context and predictability in DOE disposal decisions and asked the workshop participants for help in developing a LLW classification system that would foster greater confidence in future disposal decisions; he also admitted that these requests were tall orders.

Mr. Lovato suggested one way to think about Nevada's participation in this workshop is illustrated by a famous line from the movie *Jerry Maguire*, in which the sports agent, played by Tom Cruise, is trying to negotiate a contract for a professional athlete, played by Cuba Gooding, Jr. The sports agent repeatedly asks the athlete to "Help me, help you." The goal of the memorandum of understanding between Nevada and DOE is to "Help us, help you."

The NNSS is located about 65 miles northwest of Las Vegas. The Area 5 disposal facility is a secure, 740-acre site located in the southeast corner of the NNSS (see Figure 3-3). The disposal facility is used to dispose of mixed LLW[13] under a RCRA permit with the state of Nevada. The waste is disposed at depths of up to 24 feet (7.3 meters).

Area 5 receives less than 5 inches (13 centimeters) of annual rainfall, and depth to groundwater is 770 feet (235 meters). Infiltration of precipitation below the plant root zone ceased between 10,000 and 15,000 years ago. Consequently, migration of the waste to groundwater is less of a risk than surface erosion from thunderstorms.

NNSS accepts approximately 1.0-1.5 million cubic feet (28,000-43,000 cubic meters) of LLW, mixed LLW, and classified waste[14] per year from more than 25 different DOE facilities. This amounts to between 5 and 10

[13]LLW containing hazardous chemicals is referred to as "mixed LLW."

[14]DOE defines "classified waste" in Order 435.1 as (DOE, 1999, p. I-2): "Radioactive waste to which access has been limited for national security reasons and cannot be declassified shall be managed in accordance with the requirements of DOE 5632.1C, *Protection and Control of Safeguards and Security Interests*, and DOE 5633.3B, *Control and Accountability of Nuclear Materials*."

FIGURE 3-3 Maps of the NNSS (left image) and the location of Area 5 (middle image), and Area 5's active (yellow) and closed (gray) cells (right image).
SOURCE: Modified from DOE Office of Environmental Management.

percent of the volume of wastes disposed of across the DOE complex, including DOE wastes disposed of at commercial disposal sites (Marcinowski, 2016).

NDEP is a member of the Waste Profile Review Team. The team includes DOE, contractors, and three members of NDEP and meets weekly to review waste profiles against the NNSS WAC. If a waste stream does not meet the WAC, it will not necessarily be rejected for disposal at the NNSS. The performance assessment for the facility can be reanalyzed to determine whether the waste stream under consideration would meet the facility's performance objectives.

LLW can have a broad spectrum of characteristics. Table 3-1 provides a list of key characteristics of the LLW and mixed-waste streams considered for disposal at the NNSS. (This list was developed by Mr. Lovato based on his experiences at the NNSS.) The table shows that these waste streams have a wide range of half-lives, activities (expressed as a ratio to WAC thresholds), and plutonium equivalent grams.

Using a "plutonium equivalent grams" (PE-g) is a way to normalize the activity of different isotopes in a single package to a single standard (the activity of plutonium-239). This normalization allows for the easy determination of whether a package meets the WAC for the NNSS. (The WAC specifies a PE-g limit for each package.) The WAC for the Waste Isolation Pilot Plant (WIPP) also contains a plutonium equivalency criterion. The list of radionuclides in the WAC for the NNSS is far longer than that for WIPP, suggesting that the NNSS deals with a more diverse range of waste streams. In fact, waste characteristics at the NNSS can have a 6-17 order-of-magnitude range in values (see Table 3-1).

Waste management decisions are usually handled on a case-by-case basis to ensure that waste streams are appropriate for disposal at the NNSS and that stakeholder concerns are addressed. Some of the management steps used at the NNSS include decisions to adjust burial depth or transportation routing, conducting exercises in outreach and notification, and ensuring conditions on any waste profile approvals are met.

Case-by-case decisions can seem ad hoc, subjective, and reactive with-

TABLE 3-1 Variation of Key Characteristics in NNSS LLW Profiles.

CHARACTERISTIC	Radionuclide Half-Life (years)	Ratio of Waste Isotope Activity Level to WAC Thresholds (unitless)	Plutonium Equivalent Grams (g/m^3)
NNSS LLW RANGE	5 to 700,000,000	10^{-9} to 2×10^6	2.1 to 3,000,000

SOURCE: Modified from G. Lovato, Nevada Division of Environmental Protection.

out a reference system to compare the decisions to—especially when viewed from the outside. Nevada is interested in facilitating alternatives to disposal at the NNSS, for example by the preventing waste streams from being created and finding alternative disposal locations.

Mr. Lovato suggested a potential categorization scheme for LLW that could aid in final disposition decisions (Table 3-2). This scheme proposes a few key physical, chemical, and radiological characteristics and hazards of LLW that should be considered for its safe and secure management and disposal. Also included are key characteristics of a disposal site (i.e., location, security, and control options such as inherent and engineered barriers of a site). A new regulatory framework would break down these characteristics based on the variety of potential LLW streams and transparently list the proposed disposal criteria.

Mr. Lovato suggested that the regulatory framework should be scalable when considering new LLW streams: concerns about the new LLW stream from the waste generators, recipients, public, and DOE should be captured; options for addressing those concerns should be identified using characteristics similar to those in Table 3-2; and options for the management and disposal of a new LLW stream should be compared against each other in a transparent way. The idea is that this new framework could be created a priori without having knowledge of the LLW streams. This type of regulatory framework would be helpful in providing context on LLW disposal decisions.

Mr. Lovato encouraged the participants not to lose heart in terms of trying to develop a better LLW categorization scheme. He acknowledged that past LLW disposal decisions were likely made for expediency and were weighed against what disposal options and regulatory frameworks were available at the time. But it is incumbent upon us in the present day to improve the system, so that future stakeholders have much-needed context for the decision-making process, which may ultimately improve stakeholder confidence in LLW management and disposal decisions.

TABLE 3-2 Potential Categorization Scheme of LLW to Guide Disposition Decisions

Characteristic	Location	Potential Hazards	Control Options Criteria
Half-Life Activity Fissile Content PE-g Surface Dose Leachability	Where? (Transport?) (Disposal?)	Long Term Protection Radiation Exposure Nuclear Criticality Security	What control options should be evaluated? What criteria should be examined?

SOURCE: Nevada Division of Environmental Protection.

Dr. Robbins asked a clarifying question related to Nevada's desire to facilitate alternatives to the creation of waste streams. Was there a particular waste stream that does not fall within the NNSS' remit to accept? If so, can the NNSS discuss the possible acceptance of this waste stream with the waste generator?

Mr. Lovato explained that it is important to the NNSS and Nevada to not only look for alternative disposal options, but also alternative technologies for generating wastes. For example, the NNSS is seen as the disposal facility for sealed sources. But in Nevada's view, disposal of sealed sources should not default to a single location. So, Nevada is considering alternatives, such as reducing the use of sealed sources to begin with or by considering alternative disposal pathways, so that the NNSS is not relied on for disposal of all sealed sources.

3.2 INTERNATIONAL CASE STUDIES

Case Studies 3-4: Two Low-Level Waste Case Studies from Canada

Mr. Garamszeghy's presentation was split into three parts: background on Canadian nuclear regulation and management, a case study on the Port Hope Area Initiative (PHAI), and a case study on the Deep Geological Repository for low- and intermediate-level wastes. The PHAI disposal facility is currently under construction. The Deep Geological Repository facility for low- and intermediate-level wastes is still in the regulatory approvals phase.

There are 19 operational power reactors at four sites in Canada (three sites in Ontario and one in New Brunswick). All are CANDU[15] pressurized heavy water reactors, and all are owned by the provincially owned electric utilities (Ontario Power Generation [OPG] and New Brunswick Power). Eight of the reactors in Ontario are leased to a private firm for operation, but OPG retains the responsibility for the waste produced by these reactors and for their decommissioning. There are seven other power reactors in Canada in different stages of decommissioning. There are also seven research reactors in Canada, two reactors (one operating, the other shut down) at the Canadian Nuclear Laboratories (located near Chalk River, Ontario) and the others at universities.[16] There are numerous other historic and legacy sites undergoing decommissioning or remediation.

The Canadian Nuclear Safety Commission (CNSC) is the federal nuclear regulator, equivalent to the U.S. Nuclear Regulatory Commission

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[15] CANDU refers to CANada Deuterium Uranium reactors. For more information, see: "Canadian Nuclear Association: CANDU Technology," accessed February 25, 2017, https://cna.ca/technology/energy/candu-technology/.

[16] "Canadian Nuclear Association: Research Reactors," accessed February 25, 2017, https://cna.ca/technology/research-development/research-reactors/.

(USNRC) in the United States. Unlike Agreement States in the United States, the CNSC has not devolved any regulatory responsibilities to Canadian provinces.[17] The Canadian Environmental Assessment Agency (CEAA) is the federal agency responsible for the environmental assessment process. In the past there was a Joint Review Panel, which was a project-specific panel set up jointly by the CNSC and the CEAA, to review environmental assessment applications and specific license applications. This process is no longer used for nuclear projects. The proponent or the project owner/operator also has responsibilities as the eventual license holder. The proponents prepare the environmental assessment, the safety report, and the thousands of pages of support documentation.

The CNSC takes its authority from the Nuclear Safety and Control Act of 2000. It is a "quasi-judicial administration tribunal" that reports directly to Parliament. The commission members are independent and mostly part-time. All of the commission hearings are open to the public and are webcasted.

The CNSC has federal jurisdiction over both nuclear facilities and activities, much the same as the USNRC. It also provides regulatory oversight of all the licensees and disseminates objective scientific, technical, and regulatory information to the public—a fairly important role when it comes to public engagement for nuclear- and waste-related projects. The decisions of the CNSC can only be challenged through judicial review in federal court. The CNSC's decision making is transparent and science-based, at least in theory.

Risk assessments that apply to waste disposal include both a normal evolution scenario (climate change and gradual loss of engineered barriers) and disruptive scenarios (such as human intrusion). The assessment timeframe encompasses the time of maximum calculated impact (e.g., peak dose). In the case of a radioactive waste disposal facility, that time may be several million years in the future. The dose constraint for the normal evolution scenario is 0.3 milliseiverts per year (mSv/yr), equivalent to 30 millirem per year (mrem/yr). For disruptive scenarios, it is usually only a guideline of 1 mSv/yr (or 100 mrem/yr).

Canada has several types challenging LLW streams including:

- Higher activity wastes
  - significant amounts of carbon-14 from CANDU reactors,
  - irradiated/activated zirconium and niobium hardware from reactor refurbishments,
  - high-activity cobalt-60 waste, and

[17] Mr. Garamszeghy identified one exception as some uranium mines in Saskatchewan, which has a dual federal-provincial regulatory framework.

— stored tritium (each storage canister holds about half a million curies of tritium).

- Waste from small waste generators who may have difficulty identifying disposal pathways, especially for intermediate-level waste; and
- Large volumes of historic wastes, of which characteristics and quantities not always well documented.

The PHAI will dispose of approximately 2 million cubic meters of waste, mostly soils, in engineered mound-type facilities with multicomponent caps. This disposal will take place in two locations near Port Hope and Port Granby, located east of Toronto. The Port Hope facility is expected to be in operation in 2017; the Port Granby facility is expected to be in operation in 2018. Most of the wastes to be disposed of in these facilities are located at these facilities or nearby.

The history of the sites that are hosting these facilities can be seen in Box 3-1. The Port Hope site was used first for radium refining and later for uranium refining. These activities contaminated the site and produced large volumes of waste. A task force was established in 1988 to find a site in Canada to dispose of the Port Hope wastes. The task force was unable to reach an agreement with a community in Canada to host a site primarily because of concerns about transporting large volumes of radioactive waste.

In 1997, Hope Township initiated a proposal to construct a long-term waste management facility near the Port Hope site. The PHAI was initiated in 2001, and environmental assessments were completed for Port Hope and Port Granby projects by 2009. Part of the agreement includes the Property Value Protection (PVP) program, which will compensate homeowners should the value of their property be reduced by the presence of the facilities.

The CNSC granted the construction license for the facility in Port Hope in 2009 and a construction license for Port Granby in 2011. The federal government made a major commitment of more than $1 Canadian billion to fund the construction of the two sites in 2012.

The Deep Geological Repository for low- and intermediate-level waste will be used to dispose of OPG-owned waste (i.e., waste from the operation and maintenance of OPG-owned facilities). The repository site is located near the Bruce Nuclear Generating Station on the eastern shore of Lake Huron in Ontario.

The community near the Bruce station volunteered to host the disposal facility. The community preferred that a single facility be used to dispose of all of OPG's waste. Accordingly, a deep geologic repository was designed for co-disposal of low- and intermediate-level wastes. A near-surface facility would not have been able to accept all of the intermediate-level wastes

BOX 3-1
History of Port Hope and Port Granby sites

- **1932:** Eldorado Gold Mine Ltd. opens radium refining facilities in Port Hope, Ontario
- **1942-1954:** Production emphasis shifts from radium to uranium refining
- **1930s-1970s:** Properties and sites in the Town of Port Hope become contaminated from spillage during transportation, unrecorded, unmonitored or unauthorized diversion of contaminated fill and materials, wind and water erosion, and spread from residue storage areas
- **1976-1981:** Atomic Energy Control Board (forerunner of CNSC) directs a large-scale radiation reduction program in the Town of Port Hope (over 100,000 tonnes of contaminated soil are transferred to a site at Chalk River Laboratories)
- **1982:** Low-Level Radioactive Waste Management Office (LLRWMO) is established by the federal government to manage historic waste in the Town of Port Hope and across Canada
- **1988:** The federal government establishes a Siting Task Force on Low-Level Radioactive Waste Management to site a permanent management facility for Port Hope area wastes
- **1988-1996:** Siting Task Force invites all Ontario municipalities to consider hosting a long-term management facility for low-level radioactive waste. A few communities initially volunteer, but no agreement is reached
- **1997:** Hope Township initiates a community proposal to construct a long-term waste management facility for wastes at the Welcome Waste Management Facility
- **1998:** Port Hope and Clarington also develop proposals to establish long-term management facilities for low-level radioactive wastes within their communities
- **2000:** The Government of Canada and Hope Township, Port Hope (now amalgamated to form the Municipality of Port Hope), and Clarington initial “Principles of Understanding” outlining terms for a project to clean up low-level radioactive waste
- **2001:** The Port Hope Area Initiative begins. A legal agreement is signed that commits the federal government and the municipalities to the safe cleanup, transportation, isolation, and long-term management of historic, low-level radioactive waste
- **2002-2009:** Environmental Assessments completed for Port Hope and Port Granby projects
- **2009:** CNSC grants initial Port Hope Project licence; in 2012, 10-year licence amendment granted to complete project
- **2011:** CNSC grants 10-year licence for Port Granby Project
- **2012:** Phase 2 construction begins when the government of Canada commits $1.28 Canadian billion to complete the Port Hope and Port Granby projects

SOURCE: M. Garamszeghy, LLW presentation, Session 2, slides 14-15.

currently stored on the site. Also, a single deep geologic repository is less costly than building two separate disposal facilities.

The repository has a design capacity of about 200,000 cubic meters as packaged for disposal at a reference depth of 680 meters. Operation was originally expected to begin in the mid-2020s. The repository is currently in the regulatory review process (which is taking longer than the originally scheduled 2 years).

The official hosting agreement was signed in 2004 and was approved by the community in 2005 based on an independent poll of all year-round and seasonal residents.[18] It provides approximately $30 million in compensation to both the official host town (Kincardine) and other surrounding communities. The compensation is tied to project milestones until the repository construction is complete. After disposal operations begin, the compensation is akin to an annual fee.

The environmental assessment and licensing documentation was submitted to the CSNC in April 2011, but Canadian federal elections delayed the appointment of the Joint Review Panel until January 2012. The Joint Review Panel then implemented a public comment period that was originally planned to last for 90 days. However, the period was repeatedly extended and lasted for more than 1 year. There were, in total, 31 days of public hearings, which created 20,000 pages of documentation and more information requests from the Joint Review Panel and public. The Panel's report was submitted to the CSNC in May 2015; it strongly recommended the repository proceed to the licensing phase.

CEAA then held a public comment period. A decision by the Minister of Environment was expected in September 2015 but was subsequently extended to December. Another Canadian federal election in fall 2015 resulted in a change in government. The new minister asked for more work to be done. The responses to the minister's request are expected to be submitted by the end of 2016 with a final decision by the minister on the environmental assessment in early 2017.[19] If the minister approves the project it will move to the licensing phase.

This project has had several successes. Throughout the public review—with extensive local, national, and international scrutiny—the scientific evidence remained sound and passed all credible challenges. Despite a number of changes in government, local leadership, and residents, the politicians

[18]There is a large contingent of weekend cottage owners in the area. When the poll was conducted, both full-time and part-time homeowners were contacted.

[19]Note: the most recent update on this process was posted on April 15, 2017. The public comment period was closed on March 7, 2017. On April 5, 2017, CEAA requested additional information from OPG. "CEAA: Deep Geologic Repository Project for Low and Intermediate Level Radioactive Waste," accessed April 27, 2017, http://www.ceaa-acee.gc.ca/050/details-eng.cfm?evaluation=17520.

and the local community remained supportive. The project delays have allowed some opposition groups in Canada and the United States to organize and gain some support. Some members of the public became confused between two nuclear waste disposal projects planned in the same area, one for OPG's low- and intermediate-level waste and the other for spent fuel. Public outreach continues, and OPG continues to respond to public questions and concerns. The formal decision by the Minister will define the project's next step.

Case Study 5: The French Case: Low-Level Radioactive Waste Management

Dr. Ouzounian's case study provided insight into the French approach to disposing of very low-level waste and LLW. He noted that his presentation focused mostly on the LLW because it is more challenging and more interesting in terms of approach and process.

ANDRA is responsible for the long-term management of all radioactive waste produced in France. The agency is independent from waste producers and reports to ministers in charge of the environment, energy, and research. It has approximately 650 employees with an annual budget of €250 million. ANDRA's work is performed within the framework of the *Planning Act of June 28, 2006* on the sustainable management of radioactive materials and wastes.[20]

Safety of the population and protection of the environment are set by a national framework law and are of the highest priority in determining disposal pathways for waste. Forecasts and inventories of waste lead to a National Management Plan, which is used to identify disposition pathways for all types of waste.

There is an effort to identify a safe disposition pathway proportionate to the hazard for each type of waste. French regulations do not allow for clearance of wastes from nuclear-related activities. France uses a policy of "waste zoning" at the generator's plant to segregate waste from zones that generate radioactive waste from those that do not.

The French radioactive waste classification scheme is shown in Figure 3-4 and described below:

- Intermediate-level and low-level wastes are generated by the day-to-day operations at the nuclear power plants (NPP; green box in Figure 3-4). These wastes, previously disposed of at the Centre de la Manche disposal facility (CSM), are currently being sent to the

[20] "ANDRA: Overview of national policy concerning radioactive waste management," accessed February 25, 2017, http://www.andra.fr/international/pages/en/menu21/national-framework/overview-of-national-policy-1593.html.

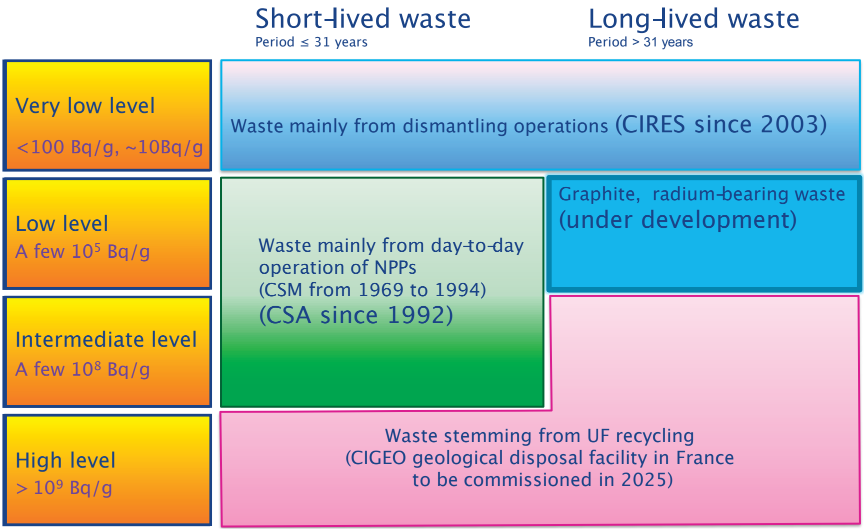

FIGURE 3-4 Classification of radioactive waste streams in France.
NOTES: Bq/g=becquerel per gram, CIGEO=Cigéo Project, CIRES= Centre industriel de regroupement, d'entreposage et de stockage facility, CSA= Centres de stockage de l'Aube, CSM=Centre de la Manche, NPP = nuclear power plant, and UF=used fuel.
SOURCE: Gérald Ouzounian, ANDRA.

Centres de stockage de l'Aube (CSA), which has been operational since 1992.

- Intermediate-level and high-level wastes are generated during uranium fuel recycling (i.e., reprocessing) (pink box in Figure 3-4). This waste will be stored in the geological disposal facility, the Cigéo Project.[21]
- Very low-level waste is generated from shut-down and decommissioning (or dismantling) operations. This waste is disposed of at the Centre Industriel de Regroupement, d'Entreposage et de Stockage (CIRES) facility (upper blue box in Figure 3-4).
- Low-level, but long-lived, waste, is generated from graphite gas-cooled reactors and, for example, from the production of rare earth metals (lower solid blue box in Figure 3-4).

[21]France has made progress toward addressing its intermediate- and high-level wastes through the Cigéo Project, constructed in a clay formation at 500 meters depth and expected to be commissioned by 2025.

Waste from small producers or other nuclear activities can span the range of waste types shown in Figure 3-4 but represents a minor part of the inventory.

There are two characteristics shown in Figure 3-4: activity levels and half-lives. Activity levels (rows in Figure 3-4) span orders of magnitude (less than 100 becquerels per gram [Bq/g] to more than 1 billion Bq/g) because there are specific threshold values for each radionuclide. Activity levels for very low-level waste range from 0 to 100 Bq/g with an average value of approximately 10 Bq/g. Waste is classified as "short-lived" or "long-lived" based on whether its half-life is less than or equal to or greater than 31 years, respectively (columns in Figure 3-4) . The 31-year half-life is approximately the half-life of cesium-137, which is 30.17 years.[22]

It is not possible from an operational standpoint to separate short-lived and long-lived radionuclides in NPP waste. There are always some long-lived radionuclides in this waste. WAC for very low-level and low-level disposal facilities in France allow for the disposal of waste containing certain amounts of long-lived radionuclides.

The principles behind radioactive waste disposal in France are, first, to contain and isolate the waste until it reaches a level of activity that does not represent significant hazard to the public or the environment (the monitoring phase in Figure 3-5). And, second, to limit the transfer of waste to the biosphere and to humans (the post-monitoring phase in Figure 3-5). As seen in Figure 3-5, the containment phase lasts for about 300 years for near-surface disposal of waste with low levels of activity and several hundreds of thousands of years for geological disposal of high-level waste.

Dr. Ouzounian described the CSA disposal facility for low-level and intermediate-level short-lived waste. The facility was licensed and commissioned in 1992 with a total capacity of 1 million cubic meters—enough capacity to contain all of the low- and intermediate-level radioactive waste generated by the present fleet of French NPPs (58 reactors). The CSA facility was designed to contain and isolate the waste for 300 years, as required by the monitoring requirement mentioned previously, and to meet the requirements for the long-term post-monitoring phase.

The French waste disposal system employs the "defense-in-depth" concept with a multi-barrier system. The system consists of the waste package, which includes a containment material enveloping the waste (the first barrier); the disposal vault, which includes a network control gallery to control water that may flow through the disposal facility and final cover (the second barrier); and the geological environment, which has natural barriers such as

[22]The *Planning Act of June 28, 2006* on the sustainable management of radioactive materials and waste specifies that the half-life cut-off between short-lived and long-lived waste is 31 years.

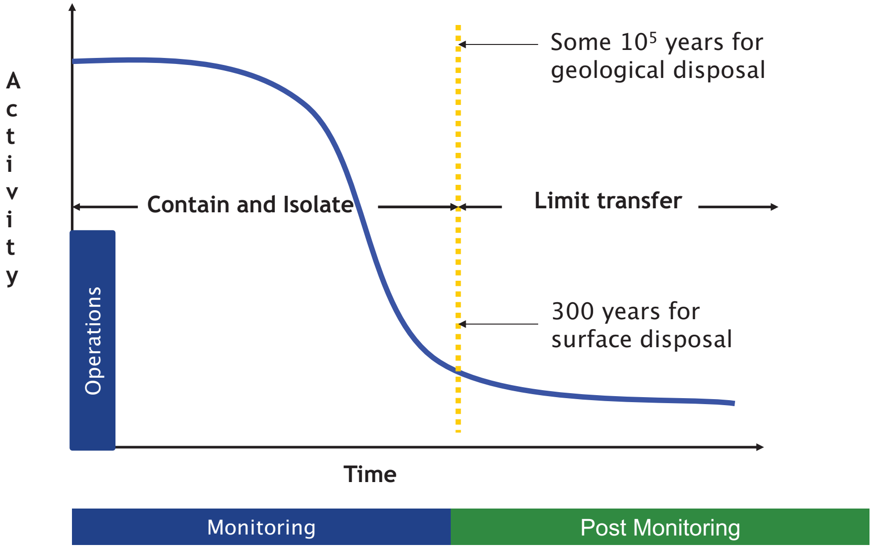

FIGURE 3-5 Disposal principles in the French radioactive waste management system.
SOURCE: Gérald Ouzounian, ANDRA.

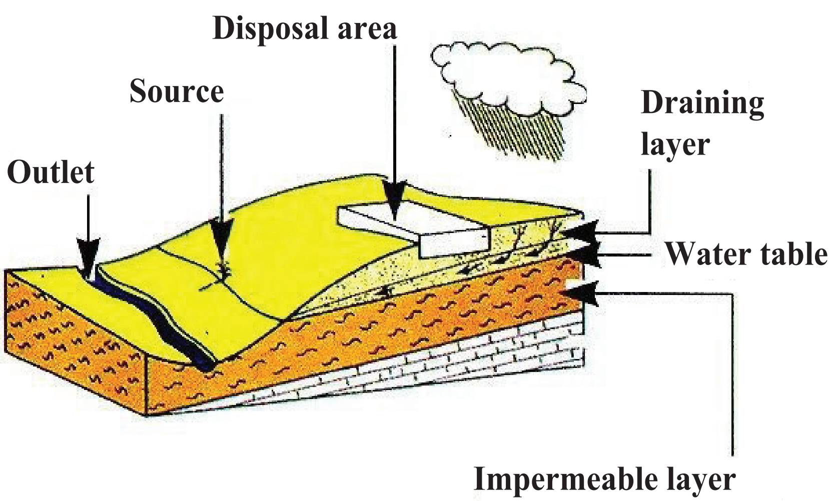

FIGURE 3-6 The French near-surface radioactive waste disposal concept.
SOURCE: Gérald Ouzounian, ANDRA.

clay to retard waste migration (the third barrier). This third barrier is the most important barrier in the post-monitoring phase.

Figure 3-6 is a schematic of the defense-in-depth disposal concept. A draining layer underlays the disposal facility, which in turn is underlain by an impermeable layer. The water table is shown with an outlet, labeled as "source" in the figure.

Inventory monitoring is essential for the effective management of radioactive waste—especially for managing long-lived radionuclides such as carbon-14, chlorine-36, and some beta emitters. NPP operators do not generally monitor for these isotopes because they do not impact daily plant operations. Therefore, the French regulator has established specific characterization requirements for these radionuclides for disposal purposes. For near-surface waste disposal, long-lived radionuclides are the major contributors to public doses in the post-monitoring phase.

Dr. Ouzounian's presentation also introduced France's approach to safety assessments, details on waste control acceptance criteria, and examples highlighting key aspects of safe operations and the defense-in-depth concept. Of particular relevance to this workshop was a discussion on the WAC for waste packages. These include:

- Radiological content
- Physical characteristics
- Chemical stability
- Gas generation
- Expected performance for long time periods
- Leaching rate
- Uniform distribution within the waste package (no hot spots)

Dr. Ouzounian provided historical perspective on the progression of safety rules, disposal concepts, and protection criteria in France. The safety rules were defined progressively, learning through the operational experiences of disposal facilities. Documents were updated and improved according to the experience of the operators—not the regulatory body. However, any changes to improve the safety rules are validated and endorsed by the regulatory body. General operational rules, and safety and radiation protection criteria, are also updated continuously.

John Applegate, the planning committee chair and executive vice president for University Academic Affairs of Indiana University, asked where the WAC (bulleted list above) came from and whether they had a risk basis. Dr. Ouzounian noted that the WAC were generated from safety assessments. Mr. Applegate also commented that experience at the prior disposal facility (CSM) appeared to be very helpful in designing the new facility (CSA), to which Dr. Ouzounian strongly agreed. All the incidents and malfunctions that occurred with the first disposal facility—which was designed without the benefit of detailed computer models—allowed for improvements to the new facility. The first safety regulations (1984 and 1985) are the result of the experiences from the first facility.

Dr. Ouzounian also noted the importance of adapting to knowledge gained from waste disposal experience in general. The process of developing an approach for the management and disposition of nuclear waste began in 1969, and much has been learned progressively. For example, it is now clear that the physical processes likely to occur should be well-understood and well-described, which requires high-quality modeling due to the long timescales involved. It is not possible to run an experiment for 100 to 300 years (or longer) to determine what may happen. The values, characteristics, and sources of hazards that are used in our assessments are the result of the models. This is why waste disposition decisions are site-specific, and also why we cannot transpose from one site to the other.

Dr. Robbins asked for clarification on one aspect of the French waste classification scheme. Is the irradiated graphite shown in Figure 3-4 considered LLW or intermediate-level waste according to the French classification scheme? Dr. Ouzounian explained that it is considered to be low-level but long-lived radioactive waste. One of the disposal options being studied is to segregate different types of graphite for disposal in different types of facilities depending on its irradiation level and activity.

3.3 DISCUSSION: KEY CHARACTERISTICS OF LLW AND CHALLENGING LLW STREAMS

Workshop chair John Applegate moderated the closing discussion on the first day's presentations. He noted that three organizing elements for managing challenging LLW streams were discussed:

- *Characteristics of the waste*. Defining waste characteristics is a technical issue. Mr. Applegate suggested that one could identify which characteristics are most important for making LLW disposal decisions. Alternatively, one could identify which characteristics are not important and are unnecessarily complicating waste disposal decisions.
- *Waste management practices*. Mr. Applegate asked whether participants could identify management practices that were unnecessarily slowing waste management decisions.
- *Regulatory framework*. Mr. Applegate asked participants to identify aspects of the current U.S. regulatory framework that are perceived to be failing. What can we learn from the experiences of other nations and international bodies? Mr. Applegate noted that

> regulatory flexibility is seen to be both useful as well as problematic. How do we manage that flexibility to make it useful, particularly with respect to increasing the predictability of the regulatory framework and/or eliminating requirements that aren't helpful?

Flexibility as a Double-Edged Sword

Kevin Crowley, director of the Nuclear and Radiation Studies Board at the National Academies, suggested that diversity and flexibility within disposal decision making is a double-edged sword. There is not much trouble handling diversity and flexibility from a technical standpoint. Where decision makers tend to fail is when they try to explain the diverse and flexible process to the people they serve. Dr. Crowley noted the importance of clearly communicating with the people who are served about the decision process: say what you are going to do, and do what you say you are going to do. Clear communication may be difficult when a system is too flexible and diverse.

Dr. Ouzounian argued that flexibility is crucially important, but it cannot be "free" flexibility. The flexibility needs to exist within a regulatory framework with clear rules, and one must be able to demonstrate that alternatives are safe and effective.

Mr. Applegate asked what a diverse and flexible framework might look like for LLW management. Mr. Garamszeghy responded that there are probably a couple approaches for establishing such a framework. One might use a performance standard, which requires a demonstration of how waste containment will be achieved. As long as the site is operated within an approved performance standard, there would be flexibility to make disposal decisions that meet that standard. This would be more flexible than a system that is based on compounding and conflicting regulations on allowable disposal options by waste type. Mr. Garamszeghy acknowledged that detailed regulations provide additional guidance to the user, but they also make it difficult to find innovative solutions when exceptions are presented.

Paul Black, chief executive officer of Neptune and Company, Inc., noted that although flexibility is critically important, cost-benefit analysis should also be considered in regulatory decisions and discussions. The current U.S. regulatory framework limits flexibility in strange ways because of competing regulatory structures. In order for the structure to change for the better, Dr. Black argued, one should strive for regulations that are simple and guidance that is process-oriented (rather than prescriptive) and based on cost-benefit considerations. The U.S. Office of Management and Budget (OMB) has the responsibility to evaluate new policies and rulemakings. As part of that evaluation, a cost-benefit analysis must be performed. OMB has developed guidance on using cost-benefit analysis.[23] Dr. Black suggested that both DOE and the USNRC should consider this guidance.

Mr. Applegate offered ALARA[24] as an example of a cost-benefit construct. Dr. Black strongly agreed and suggested that sustainability is another example. Sustainability balances three pillars: costs/economics, sociopolitical factors, and environmental factors. Dr. Black suggested that a framework for regulatory decision-making should combine the sustainability context (National Research Council, 2011b) with OMB's approach and guidance. Dr. Ouzounian noted that before cost-benefit can be assessed, safety must first be robustly demonstrated with a defense-in-depth approach.

Jennifer Heimberg, rapporteur and National Academies staff, asked Mr. Lovato whether he found it beneficial to have flexibility with the way DOE regulates over the USNRC's approach. She asked for any specific examples that showed how DOE's flexibility was utilized. Mr. Lovato noted that the NNSS does not have advance information about the variety of waste streams that will require disposal, so the DOE Orders are a good management structure for evaluating different types of waste streams. As an example, he cited radioisotope thermoelectric generators (strontium-90 sources originally from the Air Force) that required disposal. This waste had to be evaluated slightly differently from other waste streams; the flexibility in the DOE Orders allowed for that. However, he noted that it is always helpful to have a framework (e.g., the USNRC waste classification system) that can be used to explain waste management decisions to members of the public. Mr. Lovato was not advocating that a USNRC framework be used for DOE waste, but he cited it as the type of framework that is helpful for discussions with the public.

Elevating the Importance of Site Characteristics

Mr. Garamszeghy previously suggested that performance assessments be used as a framework for allowing flexibility in decisions while also providing boundaries. Mr. Applegate took this idea a step further by suggesting the following: One of the criticisms of the current U.S. regulatory framework is that it focuses on waste sources. What if the framework

[23] "Circular A-4: Regulatory Impact Analysis: A Primer," accessed March 27, 2017, https://obamawhitehouse.archives.gov/sites/default/files/omb/inforeg/regpol/circular-a-4regulatory-impact-analysis-a-primer.pdf. Circular A-4 is referenced in the Trump administration's interim guidance: https://www.whitehouse.gov/the-press-office/2017/02/02/interim-guidance implementing-section-2-executive-order-january-30-2017.

[24] ALARA is "as low as reasonably achievable" and refers to the practice of reducing exposure to ionizing radiation through every reasonable effort. "USNRC: ALARA," accessed February 25, 2017, https://www.nrc.gov/reading-rm/basic-ref/glossary/alara.html.

instead focused on disposal facilities? In other words, disposal decisions would be based on whether the waste could be safely disposed of in a facility as demonstrated by a performance assessment, irrespective of the waste source. For example, for waste potentially being sent to WCS, one would ask, "What does it take to make it safe there?"

Mr. Shrum supported this idea and restated it in another form: "Consider the waste. It can go here. It can't go there." He noted that performance assessments have been done at all of the U.S. disposal facilities and is required under 10 CFR Part 61. But Mr. Shrum noted a potential communication problem with this approach: those whom we serve do not necessarily understand the details of a performance assessment, so they will not necessarily trust the output of the analysis. He said that the members of the public often do not understand that performance assessments are used to guide—not make—decisions. He supported Mr. Applegate's approach, but he noted that effective ways would need to be developed to educate the public for this approach to be successful.

He also noted that scientific understanding of radioactive wastes and disposal facilities have grown significantly since the 1950s, when commercial radioactive wastes were first disposed of. Mr. Shrum argued that this new understanding must be used to inform current disposal decisions. The nuclear industry as a whole has not been very good at describing the technical rationale for disposal decisions to the public, and, Mr. Shrum believes, that will have to change as part of a new framework.

Dr. Crowley noted that the workshop was intended to focus on exceptions. There are many exceptions to the existing regulations and rules, and there are questions about the best way to handle exceptions in the future. One option is to change the rules to include the exceptions. But this is unlikely in the short term. Another option is to establish procedures to handle the exceptions, for example by establishing "mini rules" that may not be incorporated into the regulations. Those mini-rules could be implemented at disposal facilities using their WAC, which of course are based on performance assessments.

However, it is difficult to anticipate the full variety of wastes that might come to a facility during its design or construction stages. On the other hand, one could probably think about unanticipated wastes during the design and construction stages and determine how they might be handled. Facility-specific performance assessments are a reasonable way to proceed.

Mr. Applegate commented that Dr. Crowley appeared to have endorsed his idea of focusing on disposal facilities instead of the waste source. A disposal facility could develop WAC to which waste streams are matched. Dr. Crowley agreed that this approach could work as long as the analysis was done within the framework of the current regulations. A near-surface disposal facility is only going to take certain types of waste; the framework suggested by Mr. Applegate should not be used to try to dispose of highly radioactive waste in near-surface facilities.

Dr. Black disagreed with the approach suggested by Mr. Applegate, primarily because he is not content with current regulations for radioactive waste disposal. They are overly conservative, so WACs developed using the existing regulations will also be overly constraining. For example, the inadvertent intrusion scenario in the regulations makes no sense for arid disposal sites according to Dr. Black.

Several years ago, Dr. Black developed a performance assessment for the Nevada Test Site (now NNSS), which allowed a user to enter the characteristics of a waste stream and get an answer within hours on whether it could be disposed of at the site (DOE, 2006 and Crowe et al., 2005). Dr. Black argued that this is a better approach than WACs for evaluating whether a waste stream can be disposed of in a particular facility.

Taking Advantage of Knowledge Gained

Mr. Shrum previously introduced the idea of taking advantage of knowledge gained over decades of disposal operations, and Dr. Ouzounian also mentioned this idea in his case study. Scott Kirk, director of regulatory affairs at BWXT, raised this issue for further discussion, noting that the nuclear waste disposal industry has matured over the past 40 years. Modern state-of-the-art disposal facilities such as the WCS facility in Texas are remarkably different in siting and design than older disposal facilities such as Barnwell, which was state of the art in 1969. The modern sites are in arid environments, far removed from water tables, and designed with insights from 40 years of operating experience. These modern sites might be suitable for disposal of challenging LLW waste streams that could not be disposed of in older facilities. It would be useful to assess the suitability of current regulatory requirements against these modern facilities.

Charles Maguire, director of the Radioactive Materials Division within the Texas Commission on Environmental Quality, highlighted the current state of regulations through an analogy. Most of the huge gothic cathedrals in Europe took approximately four generations to build. The last generation to work on the cathedral had little understanding of the reasons for the size, shape, or composition of the cornerstone. Yet the cathedral was built on it, and the generations of workers that followed improved their skills as cathedral construction progressed. Mr. Maguire noted that we are about to pass our nuclear knowledge on to a fourth generation of workers. But we are telling these workers to use the same tools and techniques as previous generations. We are not "getting better."

Mr. Maguire asserted that we have to get better and to apply what we learn. We now take without question what the generation before said was essential, and we do not apply what has been learned about mitigating risk. He concluded that we need to make sure that as we build up the structure it becomes more beautiful or practical and that we are on a path to do better. Otherwise, we may end up with a regulatory framework that no one can afford to use.

From the Outside Looking In: Public Perception

Ms. Edwards suggested that terminology is important in communicating with the public, and that the LLW classification system makes clear communications difficult. Previously, one could refer to Class A LLW as a hazard that lasted about 100 years, Class C waste as a hazard that lasted 500 years, and high-level waste as a hazard that lasted tens of thousands of years. This hazard differentiation is important because the public can become confused between high-level and low-level waste. But the 1,000-year compliance period for certain types of LLW in the proposed 10 CFR Part 61 regulation blurs the previous hazard distinctions.

Mr. Camper noted that USNRC staff were trying to address the disposal of large amounts of depleted uranium and used this opportunity to add a requirement that was not previously embodied in the regulation (but should have been). The existing 10 CFR Part 61 does not specify a period of compliance but the proposed 10 CFR Part 61 rulemaking specifies a two-tiered approach to a period of compliance, i.e., Tier 1 at 1,000 years and Tier 2 up to 10,000 years.

Mr. Garamszeghy noted that the public perceives "nuclear" and "waste" as highly dangerous in part because of the complicated and prescriptive regulations that govern them. The thought is, "It must be dangerous because there are all these regulations to protect us."

Mr. Applegate asked Mr. Garamszeghy to expand on his presentation about compensating the communities in which the Port Hope and Port Granby LLW facilities were sited. Was there a "general sense of fairness" argument? Or was it seen as compensating for risk? Or simply paying for the privilege? Mr. Garamszeghy explained that the intent of the PVP program was never to, for lack of a better word, "buy" public support. Rather, it was recognized that building and operating the LLW facility would strain the local communities in terms of a number of new people coming in and wear and tear on public facilities, for example. The PVP program ensured that the local towns, communities, and people were no worse off after the facility was in place than they would be if the facility was not there.

Dr. Crowley commented on the recurring topic of public perceptions and communications. The term "educating the public" is often used. He finds this term to be denigrating because it suggests that the public is not educated and that, if it were, the public would agree with the experts' conclusions—which is not always the case. Two-way communications are required to understand the concerns that the people who live around sites have about those sites.

Dr. Ouzounian noted that the term "stakeholders" is no longer used in France. Rather, the terms "concerned" or "interested parties" are used because this involves all parties, including waste producers and academics.

He also noted that the French Parliament passed a law in July 2016 as the result of a public debate on social benefits and responsibilities. The current generation benefits from the electricity generated by nuclear power plants, so it should be responsible for solving the waste management problem for following generations. The law required that a master plan describing all the major milestones of the lifetime of each disposal facility be developed and periodically reviewed. Initially, the planned review period was 10 years. However, Parliament decided that reviews will occur every 5 years with the involvement of all concerned or interested parties.

Dr. Ouzounian also commented on compensation to local communities. Compensation is provided because of expected damage to the infrastructure and the environment, resulting for example from large numbers of trucks on the roads during construction, not from increased risk. Parliament had another important debate in 2006. One side was arguing that nuclear industries were "buying the public" by giving money to communities. The other side was argued by the high commissioner for nuclear power in France. He pointed out that one community will accept the waste that belongs to all French people benefitting from electricity. This one community shows their solidarity with the country. He argued that, therefore, it was the responsibility of the rest of France to also show solidarity by supporting the community in developing its territory and its activities. This latter argument was accepted by the Parliament and ended comments about "buying the people."

Dr. Black also commented on communication and public perception. He recalled that Mr. Shrum said that issues with LLW are more political than technical. The politics really come down to stakeholders, which means everyone associated with the disposal facility or the potential facility and the affected communities. The different outcomes for the Yucca Mountain and WIPP facilities provide a good example. In both cases, decisions on facility siting and construction were influenced by stakeholders and the political environment rather than the technical analyses. Dr. Black believes it is important to understand and "get on top of" the stakeholder issues before addressing regulatory change.

Mr. Camper spoke about the evolution of stakeholder engagement on USNRC decisions. Earlier in his career at the USNRC, staff would create new regulations and guidance documents without public input. But that changed over time for a number of reasons, not the least of which were regulatory failures. Stakeholders and interested parties demanded that decisions not be based entirely on the USNRC's scientific analyses. These demands have changed the way new regulations are developed and released.

"Regulatory Morass" Redux

Dr. Black commented that the "regulatory morass" that he referred to previously includes TRU waste. Defense TRU waste must be disposed of at WIPP, a deep geologic repository, but commercial waste containing less than 100 nCi/g of TRU nuclides can be disposed of in a near-surface disposal facility meeting the requirements of 10 CFR Part 61. Also, there are multiple regulations from DOE, USNRC, EPA, and the states for disposal facilities, some of which overlap or are in conflict.

4

The Common Themes Approach

A conceptual framework to guide future discussions and disposition decisions about challenging low-level radioactive waste (LLW) streams[1] was explored in the final session of the workshop. Case studies presented earlier in the workshop were discussed and "common themes" that led to successful disposition of previously challenging LLW streams were identified. Those themes were organized into a "common themes approach," which was initially presented by John Applegate, planning committee chair. Workshop participants were then divided into five subgroups, each focused on applying the common themes approach to a challenging LLW stream:

- Greater-Than-Class C (GTCC) waste and transuranic (TRU) waste
- Incident waste
- Sealed sources
- Very Low-level and Very Low-Activity Waste
- Depleted uranium (DU)

[1] "Challenging LLW streams," as used in these proceedings, are LLW streams that have potentially non-optimal or unclear disposition pathways due to their origin or content and incompatibility with existing standards, orders, or regulations. This is an imperfect definition as demonstrated by several of the waste streams in the list on this page. For example, many sealed sources do have disposition pathways—this workshop focused on the waste streams that are difficult to dispose of. For example, very low-level waste streams can be disposed of in existing disposal facilities, but the level of protection is not commensurate with the hazard and is therefore not optimal.

These wastes are described later in this chapter and in Appendix D. The subgroups came together at the end of the session to report their results, and the common themes approach was updated during the final discussion.

4.1 THE COMMON THEMES APPROACH

Mr. Applegate opened the session by restating the purpose of the workshop: to identify key characteristics of LLW that govern its management and disposal and to explore how those characteristics are used within existing regulatory frameworks. The workshop planning committee was not charged with inventing a new regulatory framework for LLW. Rather, the workshop used case studies to highlight successful examples of LLW management and disposal within existing regulatory frameworks.

Common themes within the case studies that led to successful disposition of the wastes were identified such as: the use of existing regulations and standards—such as the U.S. Nuclear Regulatory Commission's (USNRC's) Class A, B, and C classification scheme—to provide an anchor for disposal decisions; the identification of lessons learned from similar or analogous approaches such as Canada's or France's approach to managing and disposing of very LLW; and acknowledgement that the disposal site characteristics are as important for safe disposal as the inherent characteristics of the waste. These common themes were organized into a common themes approach that could be used within the current LLW regulations as an aid to guide decisions and direct discussions. The approach has three key elements: anchors, analogies, and adjustments:[2]

- *Anchors*: The current regulatory framework that governs LLW disposal provides a starting point for decisions about the disposition of challenging LLW streams.
- *Analogies*: Learn from successful disposition of similar wastes. Examples of past decisions for successful disposition of challenging LLW streams offer additional guidance for future waste disposal decisions.
- *Adjustments*: Use flexibility within current regulatory frameworks for making decisions about disposing of challenging LLW streams.

Existing U.S. regulations, as well as regulations and standards from international organizations, offer valuable guidance for making decisions

[2]Current USNRC regulations and the Department of Energy (DOE) policies allow for additional analyses and variances to accommodate a variety of waste characteristics. The approach described above and in Figures 4-1 and 4-3 is intended as a clarifying tool, not as a new concept.

about dispositioning challenging LLW streams. One need not write on a blank slate when making such decisions.

The common themes approach also makes use of the roughly proportional relationship between the hazard of a LLW stream and the required protectiveness of the facility that will be used for its disposal. This graphical representation could aid in discussions on identifying the levels of protection for a given level of hazard. This relationship is illustrated conceptually in Figure 4-1. The inherent hazard of the waste stream is represented on the x-axis of Figure 4-1. These hazards arise from the physical, chemical, and radiological properties of the waste stream (e.g., radiation types, activities, half-lives, and chemical toxicity).

The protectiveness of the disposal system is represented on the y-axis of Figure 4-1. The protectiveness characteristics include disposal depth, length of protection, and the number and types of barriers. Barriers can be

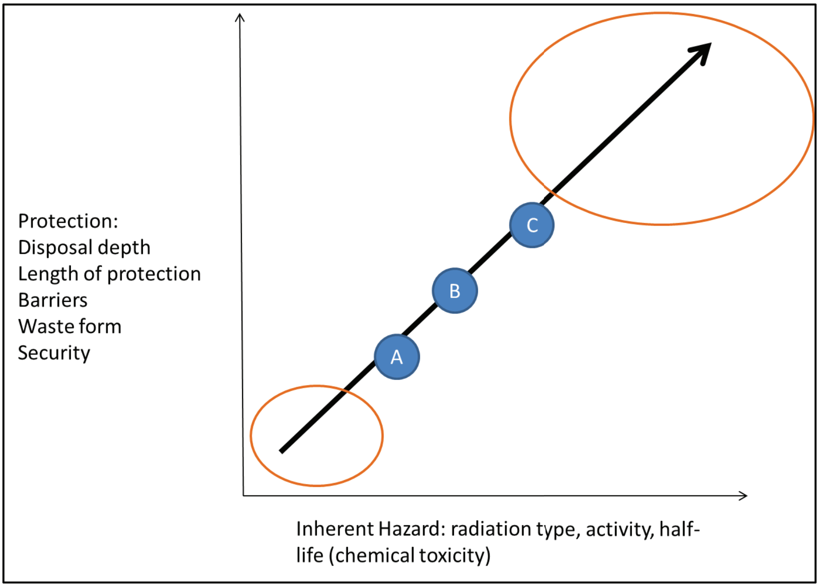

FIGURE 4-1 Conceptual representation of the "sliding scale" relationship between hazard and protection. The common themes approach for disposing of challenging LLW streams acknowledges the roughly proportional relationship between the inherent hazard of a waste stream and the level of protection required from the facility that will be used for its disposal. This proportionality is represented by the solid black line on the figure. Existing classification schemes are notionally identified by Class A, B, and C on the line and can be used as "anchors" (see text); orange circles at the upper and lower ends of the line represent the ranges of challenging LLW streams.

engineered (e.g., the waste form, engineered caps to retard water infiltration into the facility) and natural (e.g., impermeable formations underlying a disposal facility that retard waste migration). Physical security barriers (i.e., guns, gates, and guards) can also be considered if a waste stream poses a security hazard.

The solid line in Figure 4-1 is intended to be a conceptual representation of the proportional relationship between waste hazard and required disposal facility protectiveness. Class A, B, and C wastes (shown in shaded circles in Figure 4-1) have, respectively, increasingly higher levels of hazard and therefore need to be disposed of in facilities having increasingly higher levels of protectiveness. Challenging LLW streams can also be plotted on the conceptual line based on their hazards and needed levels of disposal facility protectiveness.

This type of graphical representation could help guide disposition decisions for wastes without clear or potentially non-optimal disposition pathways and could also help explain disposal decisions to non-experts. This representation is risk informed—a concept advocated by reports from the National Academies and others (National Research Council 1997, 2000, 2001, 2005, 2006b, 2011a, and Omnibus, 2015)—and is relatively easy to comprehend because it uses a small number of readily understood characteristics and shows the relationship between hazard and protection measures. This representation can also help to improve decision-making consistency for challenging LLW streams.

Mr. Applegate noted that there are not an infinite number of unknown LLW streams. Most LLW streams have been identified after many decades of nuclear activities. The waste streams that have been identified are amenable to treatment using the conceptual representation in Figure 4-1.

Planning committee member Nina Rosenberg noted that the barriers in Figure 4-1 are both natural (e.g., site characteristics) and engineered (e.g., waste forms or facility covers). Committee member Larry Camper provided guidance to the subgroups in applying the framework during the breakout session: when determining where each challenging LLW stream falls on the line in Figure 4-1, consider how that location translates to protection criteria.

4.2 DISCUSSION: THE COMMON THEMES APPROACH

Mr. Applegate asked participants for comments, criticisms, changes, or refinements to the proposed common themes approach. Lisa Edwards, senior program manager at the Electric Power Research Institute (EPRI), wondered whether the list of challenging LLW streams developed by the committee was consistent with the wastes that Department of Energy (DOE) is facing. Is very low-activity waste (or "very low-level waste" [VLLW] as previously described by Gérald Ouzounian, international director for ANDRA[3]) a big challenge for DOE, more so than for the commercial sector? Are there other volumetrically large waste streams that have not been identified for discussion in this workshop?

Doug Tonkay, director of waste disposal at DOE, stated that the list appeared to be representative of both DOE's and the USNRC's challenging waste streams. He also stated that VLLW is important to DOE because of its large volume and consumption of available disposal space. The goal for DOE is to find the best deal for the taxpayer for the safe disposal of waste.

Communications

Mr. Tonkay recalled the Session 2 discussions on communications, noting that it is very important for DOE to improve communications with its stakeholders. The tool proposed in Figure 4-1 could help. DOE has expanded communication with the state of Nevada over the past couple of years, meeting quarterly to share information about waste that is anticipated for disposal at the Nevada Nuclear Security Site (NNSS). DOE has also augmented the technical information provided in the waste profiles for potentially challenging LLW streams such as sealed sources; for example, describing how the wastes that need to be disposed of have benefitted society. Mr. Tonkay stressed that he sees communications as a key component of any future approach to guide decision making. LLW has been defined by a patchwork of laws and regulations, resulting in a wide variety of waste streams. Clear decision frameworks are needed to explain how disposal decisions are made to address the wide range of characteristics of the wastes.

Other participants also stressed the importance of communication and suggested that it be a third axis in Figure 4-1. Daniel Goode, research hydrologist at the U.S. Geologic Survey (USGS), commented on the importance for the public to understand the benefits derived from the activities that produced the waste and noted that value judgments and popular opinions within populations evolve over time.

Shape of the Line in Figure 4-1

Several participants questioned whether the shape of the line in Figure 4-1 was linear or nonlinear. Participants noted that if the curve was nonlinear, then extrapolations at its ends—where the challenging LLW streams would fall—would be difficult. Further, Class A, B, and C wastes might better be described by horizontal bars in Figure 4-1 rather than dis-

[3]ANDRA is the French acronym for National Radioactive Waste Management Agency.

crete points. One of the planning committee members noted that the figure is conceptual and intended to convey the message that the need for disposal system protectiveness increases as waste hazard increases. The common themes approach and the figure are helpful for explaining management and disposal decisions on challenging LLW streams.

Commercial Disposal Costs

Participants with commercial disposal experience noted that the costs for disposal will affect disposal decisions, particularly when there is more than one disposal option. For example, Class B waste is usually co-disposed with Class C waste, but Class B waste could potentially be disposed of separately to reduce costs. Disposal costs are a nontechnical constraint (similar to communication) that is not directly captured in Figure 4-1.

Dr. Ouzounian noted that France's approach to managing and disposing of radioactive wastes is consistent with the common themes approach and sliding scale illustrated in Figure 4-1. France has separate facilities for disposal of VLLW and LLW. The site itself is considered protective enough for disposal of VLLW—no additional barriers or protections need to be added. This leads to the factor of 15 to 18 cost savings for disposal as discussed previously in the workshop. In contrast, the protectiveness of both the waste form and the site are considered for the disposal of LLW.

Compatibility with Performance Assessment

A participant noted that the proposed common themes approach might lead to confusion or questions about the legitimacy of using performance assessment to guide decisions. A planning committee member commented that the proposed approach is meant to also guide decision making and could be used in conjunction with (and help with the communications related to) performance assessment.

Use of Chemical Toxicity in Figure 4-1

There were several questions from workshop participants about chemical toxicity and how this characteristic might be represented in Figure 4-1. Dr. Crowley noted that toxicity is a function of oxidation state, for example, and is mutable. The committee agreed that toxicity was not useful as a key characteristic and agreed to remove it from the key characteristics list in Figure 4-1. However, another participant suggested that waste mobility be added instead.

4.3 CHALLENGING LOW-LEVEL WASTE STREAMS

Mr. Applegate moderated the session on challenging LLW streams that would be discussed by the subgroups: GTCC and TRU, sealed sources, very low-activity waste, incident waste, and DU. These waste streams were described by experts from each of the subgroups in plenary session.

Lawrence "Rick" Jacobi, Jr., president of Jacobi Consulting, introduced GTCC and TRU wastes. Tameka Taplin, federal program manager in the National Nuclear Security Administration (NNSA[4]), introduced sealed sources. Lisa Edwards, senior program manager for EPRI, discussed very low-activity waste. William "Will" Nichols, principal environmental engineer at INTERA, provided an introduction to incident waste. Scott Kirk, director of regulatory affairs at BWXT, introduced depleted uranium and its disposal challenges. The biographies for these experts can be found in Appendix E.

GTCC and Commercial TRU Waste Greater than 100 nCi/g

Mr. Jacobi's overview focused mainly on technical challenges for disposing of GTCC and TRU waste. The USNRC defines GTCC waste as waste that is generally not acceptable for near-surface disposal (within 30 meters of the surface). Its waste forms and disposal methods must be more stringent than those for Class C waste. DOE has "GTCC-like" waste,[5] which is waste that is generated and owned by DOE and includes non-defense TRU waste. This GTCC-like waste has characteristics similar to commercial GTCC waste that is regulated by the USNRC. In 2015, USNRC staff recommended to the Commissioners to allow the state of Texas to license the disposal of GTCC waste (USNRC, 2015c).

TRU waste is defined in the WIPP Land Withdrawal Act as waste containing alpha-emitting transuranic nuclides (transuranic nuclides are elements with an atomic number greater than 92 in the periodic table) at concentrations greater than 100 nanocuries per gram (nCi/g) and with half-lives greater than 20 years.

In January 2016, DOE estimated the volume and activity of GTCC and GTCC-like waste in the United States to be about 12,000 cubic meters and 160 million curies, respectively. This is not a volumetrically large waste stream, but it contains a lot of radioactivity. Most of the waste is activated

[4]The NNSA is a semi-autonomous agency within DOE.

[5]GTCC-like waste is a descriptive term DOE adopted for purposes of the Environmental Impact Statement (EIS) for GTCC and GTCC-like waste. It is not a formal waste class within DOE order or U.S. regulation. This descriptive category includes both higher activity DOE LLWs and non-defense TRU wastes that do not currently have disposal pathways and that have characteristics similar to or meet the regulatory definition of GTCC LLW as defined in the 10 CFR 61 tables.

metals from the planned decommissioning of nuclear power reactors. This waste also includes sealed sources, sludge, resin, and contaminated soil. Mr. Jacobi noted that this waste inventory does not include a large number of sealed sources used by the oil and gas industries.

The DOE's final environmental impact statement (EIS) for GTCC and GTCC-like waste (DOE, 2016) proposed several disposal options for GTCC, GTCC-like, and commercial TRU waste, which include:

- A deep geologic repository, such as WIPP.
- A near-surface trench with engineered barriers.
- Above-grade vaults.
- Intermediate-depth boreholes.

Intermediate-depth (more than 30 meters below the surface) disposal is also discussed in the International Atomic Energy Agency *General Safety Guide* (IAEA, 2009a). Mr. Jacobi suggested that intermediate-depth disposal is an appropriate option and that a better name for GTCC waste might be "intermediate-depth waste."

Several participants mentioned the progressive improvement of disposal facilities over the past several decades. Early disposal practices were relatively primitive, waste forms were deficient, and performance assessment modeling was rudimentary. Waste was stored in boxes, drums, and sacks, which were dumped into trenches and covered with dirt. Modern-day disposal facilities are engineered to minimize waste. Operational practices are improved, and waste forms are more robust. Modeling capabilities and techniques are also much better.

As an example, the WCS facility in Andrews, Texas, is the United States' newest LLW disposal facility. The facility is located in an arid environment with low rainfall and a deep groundwater table; the site has low seismicity; the facility is underlain by a low-permeability clay; and the region surrounding the facility has a low population density. Additional engineered barriers have been added to the disposal facility, including compacted clay, concrete sidewalls, geo-synthetic liners, and intrusion barriers. The waste is disposed of in concrete canisters with limitations on void space in the waste as well as waste stability requirements.

Mr. Jacobi proposed that the type of reanalysis required under the USNRC's *Branch Technical Position on Concentration Averaging and Encapsulation* (BTP)[6] (see Chapter 2) would likely result in the reclassification of some portion of GTCC to Class C waste. The remaining GTCC (and possibly TRU waste) could be disposed of in a facility comparable to the

[6] "USNRC: Branch Technical Position on Concentration Averaging and Encapsulation," accessed February 26, 2017, https://www.nrc.gov/waste/llw-disposal/llw-pa/llw-btp.html.

WCS. He recommended that the United States should consider replacing "GTCC" nomenclature with "intermediate waste" following IAEA safety guidance (he noted that the rest of the world is using this nomenclature). He also recommended that future GTCC waste streams need to be considered and planned for—GTCC from Gen IV reactors is a good example. Finally, he recommended that performance assessments used to develop the USNRC waste classification system should be conducted with modern computer codes, newer standards, and data from modern LLW disposal facilities.

Sealed Sources

A sealed source is "[a] radioactive source in which the radioactive material is (a) permanently sealed in a capsule or (b) closely bounded and in a solid form" (IAEA, 2014, p. 423). There are thousands of sealed sources in use and in storage in the United States and around the world. Ms. Taplin explained that her role within the NNSA Off-Site Source Recovery Program (OSRP)[7] is to collect disused sealed sources from domestic and international locations and store and dispose of them in the United States. As mentioned previously by Mr. Tonkay, DOE provides information about the beneficial uses of sealed sources to stakeholders so that these societal benefits are considered in making disposal decisions.

Sealed sources can be highly radioactive (e.g., tens to hundreds of thousands of curies for radiotherapy or radioisotope thermoelectric generators [RTGs]), so proper packaging and transportation is a very important part of managing their disposal. Sealed sources normally have adequate documentation about their manufacture and use; this documentation is useful for planning for the disposal of these sources.

As an example of a challenge for the program, Ms. Taplin noted that occasionally the transportation certification for the packaging of a sealed source is found to be expired. This adds some complication to the recovery and for communication (i.e., the description of the process to others). DOE engages and communicates with communities along the planned transportation routes for these sources, including information about the beneficial uses of these sources.

Exempt and Very Low-Activity Waste

Ms. Edwards framed her presentation in the context of VLLW and very low-activity waste instead of clearance or exempt waste. She suggested a rough definition of VLLW as waste containing less than or equal to 10 per-

[7]OSRP's broader mission is to remove excess, unwanted, abandoned, and orphan radioactive sealed sources that pose a potential risk to national security, health, and safety.

cent of the Class A waste activity limits. She admitted that this was not a technically refined definition, but that it was a good-enough definition for the purposes of the workshop.

VLLW is a large-volume, low-activity waste stream with a low intrinsic hazard compared to other LLW streams, even most Class A waste streams. It falls on the lower part of the notional line on Figure 4-1 represented by the lower orange circle. VLLW is recognized in the IAEA radioactive waste classification scheme and in other countries as a formal waste classification. Dr. Ouzounian described how this waste classification has been successfully employed in France. Spain and other countries also use this waste classification.

One question to be discussed during the breakout session is whether the United States needs to develop a formal regulatory definition for VLLW. The USNRC exemption process (i.e., the 20.2002 exemption) is currently used to manage some VLLW streams. The exemption process allows lower-hazard waste to be disposed of in less-protective (but still adequately protective) disposal facilities than higher-hazard waste. However, the exemption process lacks transparency and can make it difficult to communicate with the public about waste-disposal decisions. The industry has asked the USNRC to publish the requirements it uses for making 20.2002 exemption decisions in a publicly available guidance document.

Some Agreement States have issued licenses to disposal facilities to accept certain VLLW streams. For example, some VLLW is approved for disposal in Resource Conservation and Recovery Act (RCRA) facilities.

Ms. Edwards argued that it would be preferable for the United States to develop a formal regulatory definition for VLLW (or very low-activity waste) that could be used to guide its disposal, rather than relying on the current exemption process. The regulatory definition would identify the key characteristics of this waste that could be used to determine its hazard for the purposes of selecting an appropriate disposal method. Having a formal regulatory definition would have a large economic impact. Ms. Edwards estimated that impact would be about $6 billion in cost savings for disposing of decommissioning wastes from U.S. nuclear plants (see Figure 2-3 in Chapter 2)—a cost savings that some have argued is a gross underestimation. The diversion of VLLW to other disposal facilities would free up capacity in LLW disposal facilities to dispose of higher-hazard waste. VLLW is expected to consume a large portion of currently available LLW disposal capacity in the United States, perhaps far into the future.

Incident Waste

For the purposes of this workshop, "incident waste" is defined as radioactive waste that would be generated from a nuclear accident or nuclear/radiological terrorist attack, collectively referred to here as a nuclear/radiological emergency. Mr. Nichols recently participated in an IAEA consultancy that developed a technical guidance document on the management of large volumes of radioactive waste that would result from a nuclear/radiological emergency.[8] He provided highlights from the draft IAEA guidance document to scope the workshop's breakout discussions on incident waste.

Much can be learned about incident waste from previous nuclear/radiological. The most important examples are the Chernobyl and Fukushima accidents, but less well-known examples can also provide important insights. For example, the 1987 Goiânia accident in Brazil resulted in extensive environmental contamination after a teletheraphy source was removed from its protective housing in a device that was left behind in an abandoned clinic. The breached source contaminated several people and sites. The Chernobyl and Fukushima nuclear accidents further highlight the need for planning for the management of large quantities of incident wastes that would be very suddenly generated following such emergencies.

The nature, scale, and timing of nuclear/radiological emergencies cannot be predicted. However, one can plan for the impacts of such emergencies, including health and safety, environmental, societal, and financial impacts. A large-scale emergency would place instant demands on national resources and present key challenges for managing incident wastes. These include characterizing and managing the waste during the emergency response and responding to public concerns about those wastes. Mr. Nichols noted that the decision making and regulatory frameworks were severely strained in the nuclear/radiological emergencies studied during the IAEA consultancy, particularly when there was no pre-planning or regulatory framework to cope with incident wastes.

Key challenges for managing incident waste are the need for (1) rapid characterization to assess its hazard and (2) waste segregation by those characterized hazard levels. Incident waste must be segregated by hazard level to be managed effectively. Otherwise, all of the waste must be managed to the highest hazard level of any of its components. Mr. Nichols suggested that proposed regulatory framework illustrated in Figure 4-1 was a good way to quickly and clearly segregate incident wastes.

Incident waste management is unlikely to get much attention in the initial stages of a nuclear/radiological emergency. But early decisions and actions could potentially have long-term, unintended consequences for waste management and disposal if not considered in planning and preparation for such emergencies.

[8]This guidance report has not yet been released.

Depleted Uranium

DU is depleted in the isotope uranium-235 relative to uranium-238. It is produced during the uranium enrichment process. Mr. Kirk provided background and history on the DU waste stream in the United States. In 1982, the USNRC promulgated 10 CFR 61, which defined uranium-containing waste as Class A waste. The analysis supporting the rulemaking considered typical or expected waste streams that were in existence at that time, such as small quantities of DU from commercial generators. In 2003, Louisiana Energy Services (now URENCO USA) proposed construction of a national uranium enrichment facility near Eunice, New Mexico, which would produce much larger quantities of DU than previous generators. DU had been determined to be more hazardous than previously thought when this enrichment facility was proposed. The USNRC commissioners directed agency staff to determine whether DU could be safely disposed of in a near-surface (i.e., within 30 meters of the surface) disposal facility. The commissioners later directed agency staff to begin a rulemaking to develop requirements that would be site specific and could be used to demonstrate that disposal of large quantities of DU could be done safely (USNRC, 2008). The final rulemaking is expected to be sent to the USNRC commissioners in the near future.

The USNRC also developed guidance for Agreement States to process requests for disposal of DU received prior to the completion of the rulemaking. This guidance suggested that disposal of DU may be appropriate in a near-surface disposal facility under certain conditions, such as when robust engineered barriers were used and/or the uranium was disposed of at greater depths.[9]

Mr. Kirk explained why DU is more hazardous than previously thought. Figure 4-2 shows the activity ratio (i.e., the activity at the waste at some future time divided by its initial activity) for typical LLW streams (solid blue line in Figure 4-2). The activity of the typical LLW stream decays to 1/100th of its original value after approximately 1,000 years. The activity ratio for DU increases almost tenfold due to ingrowth of daughter products (dotted blue line in Figure 4-2).[10] Therefore, the risk to public health and safety for disposal of depleted uranium is substantially different from other types of LLW.

The USNRC's analyses show that disposal of DU in facilities located at arid sites is adequate to protect public health and safety if the DU is

[9]This guidance has been used by Waste Control Specialists, LLC (WCS) to amend its license to allow for DU disposal at increased burial depths (i.e., 100 feet). "License Amendment Enhances Disposal Options," August 28, 2014, http://www.wcstexas.com/2014/license-amendment-enhances-disposal-options/.

[10]The decay of uranium-235 and uranium-238 produces a number of radioactive daughter products that slowly build up (or grow into) the DU, increasing its activity ratio.

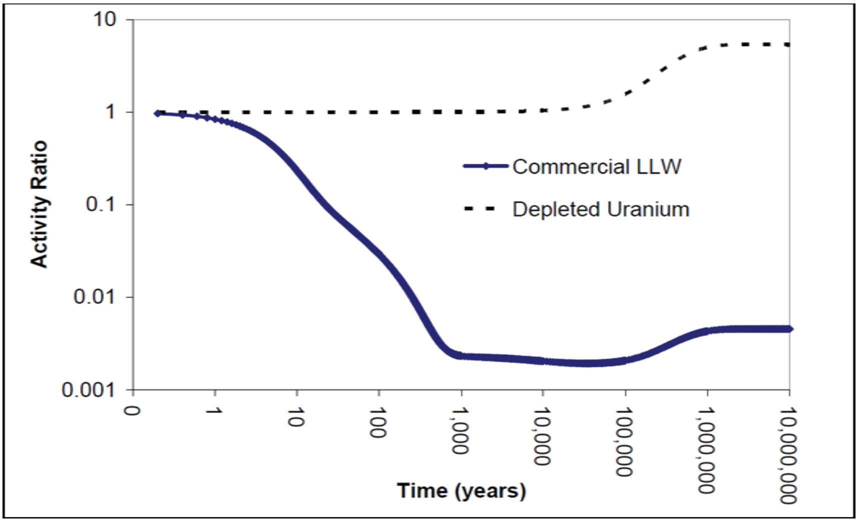

FIGURE 4-2 The activity ratio of DU as a function of time (years).
NOTE: Activity ratio is the activity of the DU at some future time divided by its initial activity. LLW = low-level waste.
SOURCE: Courtesy of James Scott Kirk, BWXT.

disposed of at appropriate depths using appropriate engineered barriers. The USNRC's proposed rule for disposal of DU suggests three tiers of protection: a 1,000-year period of compliance, 1,000-to 10,000-year assessment period, and greater-than-10,000-ear period of performance. The rule requires performance assessments to demonstrate less than 25 millirem per year (mrem/yr) (less than 0.25 milliseivert per year [mSv/yr]) exposure, an intruder analysis to show less than 500 mrem/yr (5 mSv/yr), and an analysis to show site stability.

Mr. Kirk used the WCS license application for disposing of DU to highlight examples of natural and engineered barriers. The site characteristics in the application included red clay beds (nearly as impermeable as concrete and 600 to 800 feet [180-240 meters] in thickness), the water table (about 600 to 1,000 feet [183-305 meters] below grade), and annual rainfall (approximately 15 inches [38 centimeters]) per year, with a potential evapotranspiration of about 60 inches [150 centimeters] per year). The only expected exposure pathway after disposal is through intrusion. Engineered barriers include a cover system (about 33 feet [10 meters] in thickness to retard migration of radon) and a reinforced concrete barrier surrounding the disposal site. The Texas regulator mandated that WCS dispose of DU at the deepest depth possible—which is about 120 feet (37 meters) below grade.

4.4 SUMMARIES FROM BREAKOUT SESSIONS

The discussion of breakout session summaries was moderated by Mr. Applegate. He first presented an update to and further explanation of the common themes approach in response to the earlier discussion. To recapitulate, the common themes approach consists of three steps:

- Consideration of four elements: anchors, analogies, adjustments, and anticipation, the latter element added after the earlier discussion,
- Use of an updated sliding scales graph (Figure 4-3) to connect the hazard of the waste to protectiveness of the disposal system, and
- And a new step: Review of "further dimensions," which are not included in the sliding scales graph of Figure 4-3, such as communication.

"Anticipation" was added to the original three key elements (i.e., anchors, analogies, and adjustments) in recognition that surprises can be avoided through anticipation of future waste streams. The dotted lines in

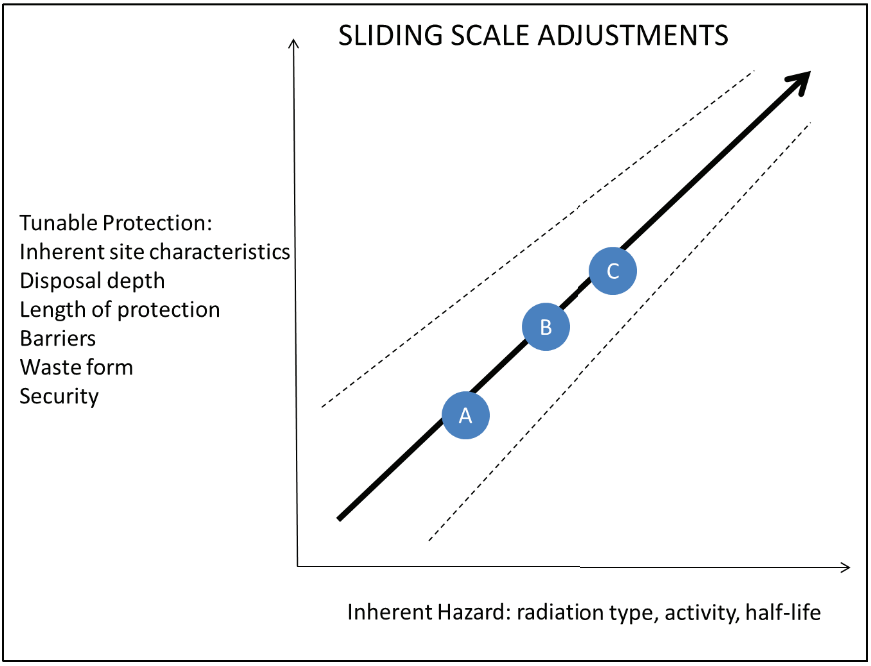

FIGURE 4-3 Updated sliding scale of hazards versus protections of the common themes approach. Changes made to Figure 4-1 based on discussion and input from workshop participants.

the updated graph (Figure 4-3) reflect the flexibility of current LLW regulatory frameworks. Note that chemical toxicity was dropped from the x-axis of the figure, and the y-axis includes both inherent site characteristics and engineered barriers for site protections.

The y-axis label was also updated to reflect the fact that the protectiveness of the disposal facility can be adjusted ("tuned") to match the waste hazard. In other words, the solid line in the graph becomes a sliding scale that can adjust waste hazard to disposal facility protectiveness.

The "further dimensions" are not shown on the updated figure. Nevertheless, they need to be considered when making disposal decisions. Such dimensions can include chemical hazards, sustainability, the beneficial activities that generated the waste (i.e., waste source), and political and public concerns.

Experts from each subgroup summarized the subgroup's discussions on applying the common themes approach to the previously identified challenging LLW streams. Subgroup members offered additional comments and identified actions that could lead to finding management and disposal decisions for challenging LLW streams.

Subgroup 1: GTCC/TRU

Mr. Jacobi summarized the discussion of the GTCC/TRU subgroup. The subgroup recognized that the USNRC, state of Texas, and WCS are currently involved in the ongoing 10 CFR Part 61 rulemaking for GTCC/TRU wastes and that each of these entities has a different perspective and approach to the problem. The USNRC's approach to updating Part 61 is to be generic in identifying characteristics and criteria, because the agency cannot create regulations with specific disposal sites in mind. However, a likely site for the GTCC/TRU wastes is WCS in Texas, which does have specific characteristics—both inherent and engineered—that make it potentially suitable for disposal of these wastes.

The subgroup concluded that Part 61 should strive to have specific technical criteria that form a baseline for analysis (i.e., the "anchor" in the common themes approach), but also that Part 61 needs to be as generic as possible—an admitted paradox. Once a site is selected, the "generic technical criteria" can be converted to site-specific technical criteria in a formal performance assessment. This would be the "adjustments" element of the common themes approach.

Several "further dimensions" were identified during the subgroup discussions. Communications and engagement with the public need to be part of the approach. Institutional challenges must not be overlooked, either. Charles Maguire, director of the Radioactive Materials Division within the Texas Commission on Environmental Quality, explained that the jurisdiction for

GTCC waste decisions in Texas has not yet been clarified by the USNRC. Until that happens, GTCC, GTCC-like, and/or TRU waste cannot be accepted at WCS.

There was a short clarifying discussion about the origin of the classification that specified the TRU waste 100 nCi/g activity level between Class C and GTCC waste. A lower threshold established in the early 1980s (10 nCi/g) was increased to the current value (100 nCi/g) because the lower value was difficult to measure and verify with then-existing survey equipment. Additionally, a "fudge factor" was added so that the application of the new threshold would result in very limited amounts of GTCC or TRU waste above the Class C threshold, or so it was thought at that time.

Mr. Kirk noted that it was recognized early on that a repository would suffice for GTCC and TRU disposal, but exceptions (described below) were provided so that a percentage of lower-hazard GTCC and TRU waste could be disposed of in a Part 61-like (i.e., near-surface) facility. Specifically, the Land Withdrawal Act for the Waste Isolation Pilot Plant defined TRU waste as waste containing transuranic elements that exceeded 100 nCi/g with a half-life longer than 20 years. But the Act provided three exceptions [WIPP, 1996, pp. 1-2]:

A. High-level radioactive waste;

B. Waste that the Secretary [of Energy] has determined, with the concurrence of the [Environmental Protection Agency] Administrator, does not need the degree of isolation required by the disposal regulations; or

C. Waste that the [US] Nuclear Regulatory Commission has approved for disposal on a case-by-case basis in accordance with Part 61 of Title 10, Code of Federal Regulations.

Some participants pointed to the increasing complexity of the regulations as problematic for disposing of these wastes. There should be a calculation of the risk of "doing nothing" when updating or creating regulations, especially when the volumes of the wastes are significant. A few participants noted that there is no immediate pressure from nuclear power plants to dispose of their commercial GTCC wastes, but DOE is pursuing the disposal of these wastes. Regardless, the USNRC rulemaking needs to move forward because the commercially stored wastes will eventually need to be disposed of.

Mr. Camper and Theresa Klickzewski, DOE, identified the following near-term next steps. Mr. Camper's suggestion was to provide comments on the GTCC rulemaking when requested by USNRC staff through Federal Register notices or public meetings. He made a similar suggestion for the expected (in the next year or so) rulemaking for TRU waste.

Ms. Klickzewski provided a few suggestions related to DOE's next actions. A DOE report required by the *Energy Policy Act of 2005* (EPAct of 2005)[11] on GTCC disposal options will soon be delivered to Congress. The Act requires DOE to await Congressional action, but it does not specify what form that action will take. DOE and Congress have agreed to hold a meeting to determine how Congress will provide its recommendations to DOE (e.g., by letter, verbally). After the recommendation is received from Congress, DOE will be able to issue a record of decision (ROD) that defines the acceptable disposal pathway(s).

Another "next step" that DOE will take in parallel is to continue to work with the USNRC as part of the 10 CFR Part 61 update process. DOE will need to receive USNRC's technical criteria for GTCC to be able to dispose of its GTCC waste.

Subgroup 2: Sealed Sources

Ms. Taplin provided a brief summary of the sealed sources subgroup discussions. Sealed sources are distinct from the other types of wastes discussed today. Sealed sources come in a variety of shapes, sizes, and activity levels. Those that contain very high-activity sources, for example sources used in irradiators, are usually doubly encapsulated and stored in heavily shielded containers. These containers can weigh thousands of pounds. The risks of radioactive material leakage from these very large sealed sources during normal handling and use is nearly nonexistent, and scenarios to calculate exposure risks are restricted to individuals with malicious intent.

An example of a challenging sealed sources waste stream is high-activity cesium sources that contain greater than 130 curies of cesium-137. This waste stream is challenging because it requires additional analysis before a disposition can be made. The upcoming USNRC *Branch Technical Position on Concentration Averaging and Encapsulation* (BTP) for Class A, B, and C waste may affect how these types of sealed sources are managed and disposed of. The determination of final disposition for this type of sealed

[11]DOE has a statutory responsibility from the LLWPA amendment to site a GTCC LLW disposal facility and explicit direction to proceed with the EIS from the *Energy Policy Act of 2005* (EPAct). From the EPAct, Sec. 631: "(B) ANALYSIS OF ALTERNATIVES.—Before the Secretary [of Energy] makes a final decision on the disposal alternative or alternatives to be implemented, the Secretary shall—

(i) submit to Congress a report that describes all alternatives under consideration, including all information required in the comprehensive report making recommendations for ensuring the safe disposal of all greater-than-Class C low-level radioactive waste that was submitted by the Secretary to Congress in February 1987; and

(ii) await action by Congress."

For more details, see "Energy Policy Act of 2005," accessed April 9, 2017, https://www.gpo.gov/fdsys/pkg/PLAW-109publ58/pdf/PLAW-109publ58.pdf.

source would be a good test of the common themes approach presented by Mr. Applegate. In fact, Figure 4-3 was used by the subgroup as a way to discuss risk reduction for a potential malicious intruder by increasing the disposal depth (but no specific depths were suggested).

Subgroup participants noted that site-specific characteristics and protections will ultimately determine whether disposal is allowable for a given type of sealed source. The subgroup agreed with the GTCC subgroup that specific technical criteria that form a baseline for analysis should be as generic as possible. For example, sealed source waste generators—hospitals, for example—would welcome an approach that did not require detailed, site-specific technical analysis for every disposal decision. If the regulations become too unwieldy for waste generators, the likelihood of the sealed sources remaining on site in storage increases, which also increases the potential risk that the sources could be stolen or weaponized in place.

Ms. Taplin and David Martin, a contractor for the NNSA, suggested a next step by the USNRC would be clear implementation guidance on the Branch Technical Position mentioned previously. It provides guidance on what can be disposed of at USNRC-regulated facilities. Sources that have activities above certain thresholds (e.g., 130 curies for cesium) require additional special analysis for disposition.

Mr. Martin noted that challenging sealed source waste streams are limited in number and identifiable (the "anticipation" step outlined in the updated common themes approach). He suggested the creation of a forum to review these challenging source waste streams and to identify what additional protections, such as inherent site characteristics, depth of disposal, and/or engineered barriers (i.e., the y-axis of Figure 4-3) would be necessary to allow these sources to be disposed of in near-surface facilities. Waste generators could use the information generated by the forum to guide disposal of these sources. Mr. Applegate suggested that disposal pathways for these sources could be explicitly identified by the forum.

Subgroup 3: Clearance or Very Low-Activity Waste

Ms. Edwards explained that this subgroup's discussion focused on very low-activity waste (i.e., VLLW) and the current approaches to disposing of it, including an exemption process within current USNRC regulations (i.e., the 20.2002 exemption discussed in Chapter 2). The subgroup did not discuss clearance or exempt waste.[12]

The 20.2002 exemption is currently used by many Agreement States and their licensed disposal facilities to dispose of large volumes of VLLW

[12] To clarify terms, "exempt waste" is not waste that has been subjected to the 20.2002 exemption process. Further, the 20.2002 exemption process does not reclassify the waste—it remains LLW.

in RCRA-like facilities. For example, WCS is currently authorized through this exemption process to dispose of LLW by means other than those defined in 10 CFR Part 61 as long as certain requirements are met, such as the waste streams have very low activities. The process grants an exemption to RCRA facilities to receive VLLW, subject to certain requirements by the state regulator.

Other organizations have different ways of managing VLLW. DOE, which is self-regulating, uses the "authorized limits process" to dispose of wastes with low levels of radioactivity at on-site disposal cells. France has a separate classification and disposal process for VLLW as discussed earlier in the workshop.

One could point to the 20.2002 exemption, or the authorized limits process, as "anchors" for VLLW. Alternatively, the French classification system could be used as an "anchor" or "analogy" should the United States decide to add a classification level for VLLW. In fact, Ms. Edwards noted that the subgroup supported the idea of adding a new classification category for this waste type.

The subgroup thought it would be easier to describe VLLW disposal decisions to stakeholders and the public through a new classification than through the current exemption process, which is complicated, granted on a case-by-case basis, and lacks transparency. The terminology is also confusing: VLLW is reviewed through an exemption process for disposal at a RCRA facility, but the waste is not "exempt" waste. There is also the need to reserve space in LLW disposal sites for wastes that pose a higher hazard than VLLW as noted previously.

Dr. Goode suggested that an independent study be commissioned to review the current status and processes for disposing of VLLW. The study should identify the volumes and activities of VLLW in the United States and its possible disposal pathways. The study would provide a broad but thorough picture of the U.S. approach to the disposal of this waste and would inform the scientific community and the public.

Andrew Orrell, section head for waste and environmental safety at the IAEA, identified a slight tension between the interests of DOE and commercial parts of the disposal system, specifically with respect to the introduction of a new waste category versus anxiety by commercial facilities, for example, about changes to the current regulatory structure. He recommended the creation of a task force to help decide whether creating another waste category would actually result in cost savings for industry and enhance public understanding.

Subgroup 4: Incident Waste

Mr. Nichols summarized the subgroup's discussion and attempted to link it directly to the common themes approach, outlined by Mr. Applegate at the start of the session. What are the characteristics of the anticipated waste? Incident waste is highly heterogeneous, including radioactively contaminated biological materials (e.g., plants, agricultural products, and animals), infrastructure (e.g., buildings, vehicles), liquids,[13] and ion exchange resins used to remove contamination from liquids. The quantity of waste is potentially large, rapidly produced, and geographically distributed. Incident waste potentially covers the range of hazards in Figure 4-3.

The challenges for disposing of incident waste are many:

- Characterization and segregation of the waste will be challenging given its volume and distribution. Waste management will not be the highest priority during the initial response to a nuclear/radiological emergency, but early decisions on segregation could have long-term impacts on disposal options.
- Identifying the disposition endpoints (i.e., how clean is clean enough?) will require input from stakeholders and will help determine what areas are cleaned up and to what extent.
- Waste storage sites will need to be found or designated until the waste can be disposed of.
- The capacity of existing LLW disposal sites could easily be overwhelmed by a single large-scale nuclear/radiological emergency.

The subgroup identified preplanning as a critical component in addressing these challenges. The wastes would initially be characterized and segregated by activity level to manage the threat/hazard, but it should not be subject to waste classification at this initial stage. In fact, some in the subgroup thought that "incident waste" ought to be established as a separate waste classification and that performance assessment be used to guide its management.

Mr. Tonkay noted that the right of eminent domain should be added to the challenges for management of incident waste—or perhaps to the "further dimensions" step. Citizens' property could become contaminated as a result of the event. Initially, it might be clear that property owners and citizens should evacuate, but preplanning could help to clarify when they can be allowed to return and how their contaminated property will be dispositioned.

Mr. Nichols suggested that a next step would be to consider creating a special category for incident waste, recognizing of course that such wastes

[13] For example, contaminated liquid wastes from building decontamination and waste removal activities.

would have to be managed using a risk-informed approach. Also, a regulatory analysis needs to be included in the emergency planning to determine how the classification might hinder or help recovery actions.

Dr. Crowley added a few comments. He noted that the Environmental Protection Agency (EPA) has done significant work on Protective Action Guidelines (PAGs), which at least provide a conceptual understanding of what to do from a protective standpoint. However, there is less understanding of how to deal with the waste itself. There have been a couple of unintentional experiments, the Chernobyl and Fukushima accidents. A next step, if not already done, would be to see how incident waste from those accidents was handled and what lessons could be learned. This information could be used to develop guidance for policy makers in the United States about how to respond to future nuclear/radiological emergencies. He also noted that incident waste is not likely to be a problem for DOE unless there was an accident at a DOE site. Rather, an accident/attack was more likely to occur in the civilian sector, for example a nuclear plant accident or a terrorist attack on a major city.

Mr. Orrell noted that the IAEA is almost ready to release two publications on incident waste: a safety guide and a technical document on preparing for and managing incident waste. Dr. Ouzounian noted that in France they have prepared and practiced a concept for managing waste from emergency situations, a concept that has been in place for a few years.

Subgroup 5: Depleted Uranium

Mr. Kirk noted that there is a well-known amount of DU and that work has focused on identifying the right waste form. Most DU is in the form of uranium hexafluoride (UF_6)[14] in cylinders. DOE recognized early on that UF_6 would have to be converted into a more stable solid such as uranium oxide (e.g., U_3O_8) to make it suitable for disposal.

Mr. Kirk noted that the newly added dashed lines in Figure 4-3, representing the flexibility of existing regulatory frameworks, were also appropriate “anchors” for DU, which grows more radiotoxic (from Class A waste to higher classes) as daughter products grow in over time (Figure 4-2). Pathways for disposition of a significant amount of DU have already been determined—for example, DU has been disposed of at the EnergySolutions LLW disposal facilities at Hanford, Washington, and Barnwell, South Carolina. DU may also be appropriate for disposal at more modern LLW disposal facilities, for example the WCS facility in Andrews, Texas—subject to the completion of the final 10 CFR Part 61 rulemaking.

[14] At atmospheric temperature and pressure, UF_6 is a solid. It will sublime into a gas at 134°F (57 °C) and ambient pressure.

Existing regulatory protection standards were discussed as "analogies" within the common themes approach. For example, the WCS license contains a general prohibition against disposal of large quantities of DU, but there was also an activity limit of 10 nCi/g—meaning that DU could be disposed of if its activity is less than 10 nCi/g.

The rulemaking poses some regulatory hazard to facilities that have already disposed of DU. It is possible that the rulemaking will require that additional protections be added at older facilities that have disposed of DU as Class A waste. (The rulemaking could affect other waste streams that have been disposed of as Class A waste.) Mr. Garmaszeghy noted that the wastes currently disposed of at disposal facilities are subject to changes in regulations. Daniel (Dan) Shrum, senior vice president of regulatory affairs at EnergySolutions, noted that facilities have to comply with changes in USNRC regulations, even for waste that has already been disposed of, on a case-by-case basis.[15]

Mr. Kirk suggested two steps that could be taken to advance the decision-making process for disposal of DU. The first is for DOE to complete its National Environmental Policy Act (NEPA) review[16] and, second, for the USNRC to finish the 10 CFR Part 61 rulemaking. The NEPA review is a requirement before federally owned DU can be disposed of at commercial facilities. The facilities will need to review the updated Part 61 rulemaking to determine its meaning and impacts. Mr. Shrum noted that the EnergySolutions LLW Disposal Facility in Clive, Utah, is working on a DU performance assessment to amend its existing license to accept large quantities of DU. The assessment had been dropped to a lower priority, but there is renewed focus by EnergySolutions to finish the assessment so that the state regulator can evaluate it.

Mr. Camper commented that 10 CFR Part 61 is based on an EIS that was prepared at the time the regulation was created, but the EIS has never been updated. Facility design and operation assumptions that were used in the original EIS may be different from modern facility designs and operations. For example, the EIS did not envision disposal facilities like WCS in Texas or EnergySolutions in Clive, or even the changes to facility designs and operations that have occurred at the EnergySolutions LLW disposal facility in Barnwell, South Carolina. Also, the volumes and types of LLW

[15] See USNRC 10 CFR 61.1: "(a) … Applicability of the requirements in this part to Commission licenses for waste disposal facilities in effect on the effective date of this rule will be determined on a case-by-case basis and implemented through terms and conditions of the license or by orders issued by the Commission." Accessed March 29, 2017, https://www.nrc.gov/reading-rm/doc-collections/cfr/part061/part061-0001.html.

[16] "DEPARTMENT OF ENERGY Notice of Intent To Prepare a Supplemental Environmental Impact Statement for Disposition of Depleted Uranium Oxide Conversion Product Generated From DOE's Inventory of Depleted Uranium Hexafluoride," posted August 26, 2016, https://energy.gov/sites/prod/files/2016/08/f33/EIS-0360-S1-NOI.pdf.

being disposed of at these facilities are remarkably different from original assumptions. The USNRC should update the EIS to represent actual waste streams and disposal facility designs and operations. The existing EIS is difficult to amend, and a new EIS is expensive to develop. If a new EIS is not feasible, then an independent study or analysis could be carried out to more accurately capture modern LLW disposition practices. Such a study could be funded from DOE, USNRC, and possibly industry. The general public, as well as other countries, would also benefit from this analysis.

4.5 FINAL THOUGHTS: REVIEW OF THE COMMON THEMES APPROACH

Mr. Applegate asked the participants for final thoughts on using the decision framework (or, as he referred to it, the Common Themes approach). Ms. Klickzewski's comment was that federal agencies should *do something*. They should take an action to show movement and progress. Whether it is the BTP from the USNRC, or a ROD from DOE on GTCC waste, or the NEPA for DU, action is needed. Mr. Applegate agreed with her comment. He was surprised at the activity that has already taken place for many of the waste streams and wondered why they are seen as "challenging" by DOE and the USNRC. He hypothesized that perhaps the final disposition decisions are actually close to being made—or closer than it was assumed when the workshop was requested by DOE.

Mark Yeager, division of waste management at South Carolina's Department of Health and Environmental Control, noted that states deal with multiple regulatory regimes: DOE, the USNRC, and the EPA. He suggested that these three agencies come together to develop an integrated approach for regulation of LLW, perhaps using the *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM) as a model. He stressed that until there is a consistent and complete regulatory framework across the regulatory agencies, it will continue to be difficult to gain confidence from the public. Ming Zhu, acting budget director for DOE's Office of Environmental Management, agreed with the need for integration across agencies and noted that this was a key finding from a recent omnibus risk review,[17]

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[17]The Consolidated Appropriations Act, 2014 (referred to as the "Omnibus") (Omnibus, 2015, p. v) directed DOE to "retain a respected outside group . . . [to] undertake an analysis of how effectively [DOE] identifies, programs, and executes its plans to address risks [to public health and safety from the DOE's remaining environmental cleanup liabilities], as well as how effectively the Defense Nuclear Facilities Safety Board (DNFSB) identifies and elevates the nature and consequences of potential threats to public health and safety at the defense environmental cleanup sites." See "A Review of the Use of Risk-Informed Management in the Cleanup Program for Former Defense Nuclear Sites," accessed March 2, 2017, http://www.tri-cityherald.com/news/local/hanford/article33023001.ece/BINARY/Omnibus%20Risk%20Review%20Report_FINAL.

which also concluded that within EPA there is need to integrate regulatory requirements, policies, and guidance under Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, known also as Superfund) and RCRA (Omnibus, 2015, pp. viii-ix). Dr. Zhu further commented that agencies are already actively engaging in the use of performance assessments to guide risk-informed decisions on managing wastes. He noted that agencies have come together in recent years to compare processes and develop lessons learned and best practices in conducting performance and risk assessments for supporting decision making, including on disposal facility operations.

Ms. Edwards agreed that a comprehensive picture of the regulations across agencies would be valuable. To be able to show that there is a single framework guiding decisions on LLW disposal would be useful. Such a framework might also be able to show how different rules and regulations across the agencies work (or do not work) together.

4.6 FINAL THOUGHTS: COMMUNICATION

Mr. Applegate started the discussion about communications by talking about the meaning of the term "stakeholder." He noted that there are many people involved with or affected by LLW disposal who have many different perspectives, levels of understanding of the issues, and objectives. He asked participants to describe what steps could be taken to improve communications with these different groups.

Ms. Edwards responded that communication and transparency with the public are important throughout the entire lifecycle of LLW. We are deficient in communicating about LLW not only because the system is difficult to explain, but also because radioactive waste is portrayed as a "boogeyman." One approach is to avoid public discussion altogether, but this is a very short-sighted perspective. It may be difficult to communicate about the good protective measures that are being taken with radioactive waste, but it is our job to do so.

She recalled Dr. Goode's comments about the public's perception of a waste being affected by the perception of how the waste was generated or stored. For example, there may be more public support for disposal of radioactive waste from medical treatments than from weapons development or for the disposal of sealed sources to reduce terrorist threats. Even if the waste characteristics and hazards are similar, the fact that it was generated from different processes influences public perceptions. Perhaps there is an opportunity to communicate with the public about wastes it perceives as being generated from processes that are acceptable or valuable. It would at least open the possibility of a discussion of actual hazards and technical solutions that could be used to address those hazards. One could then explain how waste from other processes could be managed. It would also be an opportunity to discuss disposal options that are commensurate with the level of hazard posed by the wastes.

Dr. Crowley noted that we have to change the way we talk to our stakeholders, as he explained earlier in the workshop (i.e. "educating the public"). He provided several suggestions. The first is to understand that there is not *a* public, there *are* publics. There are many different people at different levels that we need to communicate with, for example state legislators, city councils, concerned citizens, or even the League of Women's Voters. We have to understand who those audiences are, and then we have to understand what they are interested in. And to do that, we have to go out and ask them. Communication begins with discussions with the publics to find out what their interests are and what their questions are. And then you have to try to answer those questions. A true dialogue is needed.

These concepts are well understood but difficult to implement. Dr. Crowley explained that the National Academies try to implement this approach for communicating with the public in some of the studies that they carry out, and he knows from these experiences that this type of communication is very difficult to do because we operate in a very low-trust environment, particularly with respect to the government. Dr. Crowley suggested that improving communications will be a long-term effort, and that it will take a long time to establish sufficient trust to have a useful dialogue.

Mr. Garamszeghy noted that the use of the term "talking to the public," which has repeatedly been raised throughout the workshop, is indicative of the wrong attitude. Talking "at the public" or "to the public" turns people off. As mentioned by Dr. Crowley, it is necessary to talk *with* members of the public to understand what their concerns and issues are. Ask them what their needs are. Communication is a two-way street. Members of the public want to know and feel that they are being respected, their views are respected, and their input is valued.

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Appendix A

Statement of Task

The National Academies of Sciences, Engineering, and Medicine will convene a workshop of domestic and international technical, regulatory, and policy experts to discuss the safe and secure management and disposition of low-level radioactive waste. The workshop presentations and discussions will address the following topics:

- Identification of key physical, chemical, and radiological characteristics of low-level radioactive waste that govern its safe and secure management (i.e., packaging, transport, storage) and disposition, in aggregate and for individual waste-streams.
- How key characteristics of low-level waste are incorporated into standards, orders, and regulations that govern the management and disposition of low-level radioactive waste in the United States and in other major waste-producing countries.

A summary of the workshop discussions will be prepared by a designated rapporteur. The summary will not contain consensus findings or recommendations.

Appendix B

Biographies of Planning Committee and Staff

JOHN S. APPLEGATE (*Chair*) is executive vice president for University Academic Affairs of Indiana University (IU) and the Walter W. Foskett Professor of Law in the IU Maurer School of Law. He has served as a vice president for IU since 2008. He teaches and has written extensively in the fields of environmental law, administrative law, regulation of chemicals and hazardous wastes, international environmental law, risk assessment, and the management of radioactive waste. He chaired the Fernald Citizens Advisory Board at the Department of Energy's (DOE's) Fernald facility in Ohio from 1993 to 1998, and he served on the DOE Environmental Management Advisory Board from 1994 to 2001. He has also served on several Academies studies. A member of the American Law Institute, Professor Applegate has also taught at the University of Paris (Panthéon-Assas) and University of Erlangen-Nürnberg and has been a research fellow at Cardiff University. Before moving to Indiana, he was the James B. Helmer, Jr., Professor of Law at the University of Cincinnati College of Law and was a visiting professor at Vanderbilt University Law School. He was a judicial law clerk for the U.S. Court of Appeals for the Federal Circuit and an attorney in private practice in Washington, D.C. Professor Applegate received his B.A. in English from Haverford College in 1978 and his J.D. from Harvard Law School in 1981.

LARRY W. CAMPER is an executive consultant with Advoco Professional Services, LLC, and senior nuclear safety consultant with Talisman International. Mr. Camper retired from the U.S. Nuclear Regulatory Commission (USNRC) in September 2015, as the director of the Division of Decommissioning, Uranium Recovery and Waste Programs. For the preceding 10 years, Mr. Camper served as the director of the Division of Waste Management and Environmental Protection in the Office of Federal and State Materials and Environmental Management Programs. Prior to assuming that position, Mr. Camper served in several Senior Executive Service positions within the USNRC including: 2 years as the deputy director, Spent Fuel Project Office; 4 years as the chief, Decommissioning Branch; and 4 years as the chief, Materials Safety Branch. Mr. Camper also served for 10 years as the U.S. Representative to the Waste Safety Standards Advisory Committee of the International Atomic Energy Agency in Vienna, Austria. Mr. Camper is an experienced health physicist, radiation safety expert, environmental remediation expert, and executive. He has more than 40 years of professional experience with various aspects of the nuclear industry within both the private and public sectors including: radiation safety; medical, research and academic uses; commercial uses; industrial uses; environmental assessment and management; LLW oversight; uranium recovery; decommissioning of reactors and complex material sites; and spent fuel management and performance assessment. Mr. Camper received a B.S. degree in radiological science and administration (School of Medicine and Health Care Sciences) and an M.S. degree in administration (School of Business), both from George Washington University. Mr. Camper also completed graduate course work in applied health physics at Oak Ridge Associate Universities, and he completed a graduate-level Certificate in Implementation of the National Environmental Policy Act from Duke University, co-sponsored by the Council on Environmental Quality. Mr. Camper completed a certificate in Strategic Management of Regulatory and Enforcement Agencies at Harvard University, John F. Kennedy School of Government, Executive Education.

JENNIFER A. HEIMBERG is a senior program officer in the Division of Earth and Life Studies (DELS) and the Division of Behavioral and Social Sciences and Education (DBASSE). In her work for the Nuclear and Radiation Studies Board in DELS, she has focused on nuclear security, nuclear detection capabilities, and environmental management issues, and she has directed studies and workshops related to nuclear proliferation, nuclear terrorism, and the management of nuclear wastes. She directed a DBASSE study on assessing approaches for updating the U.S. metric known as the Social Cost of Carbon. Previously, she worked as a program manager at the Johns Hopkins University Applied Physics Laboratory, where she established its nuclear security program with the Department of Homeland Security's Domestic Nuclear Detection Office. She has a B.S. in physics from Georgetown University, a B.S.E.E. from Catholic University, and a Ph.D. in physics from Northwestern University.

REBECCA A. ROBBINS is currently the predisposal unit head at the International Atomic Energy Agency (IAEA) in Vienna, Austria. In this role she is responsible for working with IAEA member states to develop and disseminate IAEA guidance in all aspects of the processing, packaging, and storage of all type of radioactive waste. She has more than 20 years of experience in the nuclear industry in both the United Kingdom (UK) and the United States. Dr. Robbins has supported and led projects related to the cleanup of legacy wastes including transuranic waste at Idaho National Laboratory site and Hanford tank waste. She earned a Ph.D. in inorganic chemistry from the University of Leeds, UK.

NINA D. ROSENBERG has 25 years of experience in both technical and leadership roles at two of DOE's National Nuclear Security Administration national laboratories. She is currently the program director of Nuclear Nonproliferation and Security at Los Alamos National Laboratory (LANL). Dr. Rosenberg previously worked at Lawrence Livermore National Laboratory from 1998 to 2011. Also, she was a staff scientist in the Earth and Environmental Sciences Division at LANL from 1991 to 1998. Dr. Rosenberg is a geoscientist with experience in subsurface contaminant transport and remediation, water resources, and geologic repositories for nuclear waste. She received a B.A., summa cum laude, in geological and geophysical sciences from Princeton University and an M.A. and Ph.D. in geological sciences from the University of California, Santa Barbara.

Appendix C

Workshop Agenda

Low-Level Radioactive Waste Management and Disposition: A Workshop

October 24–25, 2016
Keck Center
500 5th Street, NW
Washington, DC 20001

Monday, October 24

9:00 am Welcome
John Applegate, organizing committee chair
Executive Vice President for University Academic Affairs, Indiana University

Jenny Heimberg, study director
Nuclear and Radiation Studies Board, The National Academies

Opening Remarks
Douglas Tonkay
Director, Office of Waste Disposal, Office of Environmental Management, Department of Energy (DOE)

9:15 am Workshop Background and Objective
John Applegate, organizing committee chair

Session 1: The Scope of the LLW Challenge

9:45 am Categories and Characteristics of Low-Level Waste (LLW)
Moderator:
Nina Rosenberg, organizing committee member
Program Director, Nuclear Nonproliferation and Security, Los Alamos National Laboratory

Each of three panelists will outline the variety of LLW streams, followed by a moderated, full-panelist discussion.

Questions for panelists:
- What are the greatest challenges that you have observed in the management of LLW?
- What key technical criteria and/or waste characteristics are most important to consider?

Miklos (Mike) Garamszeghy
Design Authority and Manager, Technology Assessment & Planning Nuclear Waste Management Organization (NWMO), Canada

Lisa Edwards
Electric Power Research Institute (EPRI)

Daniel B. Shrum
Senior Vice President Regulatory Affairs, EnergySolutions

11:00 am BREAK

11:15 am Regulations, Standards, Orders, and Guidance Criteria
Moderator:
Larry Camper, organizing committee member
Nuclear Safety Consultant, Advoco Professional Services, LLC; U.S. Nuclear Regulatory Commission (USNRC), retired

Each of three panelists will answer a set of questions, followed by a moderated discussion.

Questions for the panelists:
- What are the health, environmental safety, and security bases that led to the generally applicable standards and regulations in your line of work?
- What are the strengths and weaknesses of the respective approaches?

Andrew Orrell
Section Head for Waste and Environmental Safety, International Atomic Energy Agency (IAEA)

Thomas Magette
Managing Director, PricewaterhouseCoopers Advisory Services, LLC

Mark A. Yeager
Environmental Health Manager, South Carolina Department of Health and Environmental Control

12:30 pm LUNCH

Session 2: Lessons Learned in Establishing LLW Disposition Pathways

1:30 pm Case Studies of Successful LLW Disposal Solutions
Moderator:
Rebecca Robbins, organizing committee member
Predisposal Unit Head, IAEA

United States case studies

Case Study 1:
Separations Process Research Unit (SPRU) Tank Waste Sludge Case Study
Melanie Pearson Hurley, DOE-EM Headquarters Site Liaison for the SPRU project

Case Study 2:
Low-Level Radioactive Waste Streams Reviewed for Disposal at Nevada National Security Site—Key Criteria, Variation, and Management
Greg Lovato
Deputy Administrator, Nevada Division of Environmental Protection

Questions for the panelists:

- What were the key characteristics of the waste stream that affected management decisions for waste processing, transportation, storage, and disposal?
- Why did it work? Lessons learned for management from each example.
  - —waste characteristics (technical)
  - —management practices (process)
  - —regulatory structure (manageable, predictable, consistent)
- Were there instances in which it almost did not work?
- What were the obstacles to successful waste management and disposal?
  - —waste characteristics
  - —management practices
  - —regulatory structure

2:30 pm BREAK

2:45 pm Case Studies of Successful LLW Disposal Solutions (continued)
Moderator:
Rebecca Robbins, organizing committee member

International case studies

Case Study 3:
Canada, Licensing a Low-Level Waste Facility
Case Study 4:
Deep Geologic Repository for Low- and Intermediate-Level Waste Repository
Mike Garamszeghy, NWMO

Case Study 5:
France, Very-Low-Level and Intermediate-Low-Level Waste facilities
Gérald Ouzounian, Director, International Division, ANDRA-Agence nationale pour la gestion des déchets radioactifs

Questions for the panelists: (see questions for U.S. case studies

Full Workshop Discussion

3:45 pm Key Characteristics of LLW and Challenging LLW Streams: Initial Discussions
John Applegate, organizing committee chair

4:45 pm Wrap-up
John Applegate, organizing committee chair

5:00 pm ADJOURN

Tuesday, October 25

9:00 am Welcome
John Applegate, organizing committee chair, and
Jenny Heimberg, study director

9:10 am Common Themes from Yesterday's Discussions (Characteristics and Methodologies)
Moderator:
John Applegate, organizing committee chair

10:10 am BREAK

Session 3: Applying Common Themes to Problem Cases

10:25 am Moderator:
John Applegate, organizing committee chair

Description of the problem case studies by experts:

1. Greater than Class C (GTCC) and Commercial Transuranic (TRU) Waste > 100 nCi/g
   Lawrence R. Jacobi, Jr., Jacobi Consulting
2. Sealed Sources
   Temeka Taplin, NNSA
3. Clearance or Exempt Waste and Low-Activity Waste (e.g., lowest 10% Class A Waste)
   Lisa Edwards, Electric Power Research Institute (EPRI)
4. Incident Waste
   Will Nichols, INTERA
5. Depleted Uranium (DU)
   Scott Kirk, BWXT

10:50 am BREAK-OUT Session

Evaluating the Usefulness of Common Themes Applied to Problem Cases

Organizing committee members and study director to each lead a breakout group.

Each group will be encouraged to think about the challenges of one particular waste stream in light of previous remarks.

- What are the characteristics of the wastes?
- What are the challenges to disposal?
- How might the proposed methodology or approaches be applied to this WWP category?

12:00 pm LUNCH

1:00 pm Summary of Morning Session by Each Group Lead

2:15 pm BREAK

Session 4: Concluding Discussion

2:30 pm Full Workshop Discussion
Moderator:
John Applegate, organizing committee chair

- What have we learned? Do we have the pieces here for an integrated solution/system for LLW without a disposition pathway?
- Is there information missing that keeps us from developing an integrated solution?

4:00 pm Concluding Remarks/Reactions from Agencies
Douglas Tonkay, DOE-EM

4:15 pm Wrap-up
John Applegate, organizing committee chair

4:30 pm ADJOURN

Appendix D

Low-Level Radioactive Waste Management and Disposition: Background Information

The Department of Energy's Office of Environmental Management (DOE) is responsible for the cleanup of sites used by the federal government for nuclear weapons development and nuclear energy research. DOE "cleanup" involves the retrieval, treatment, storage, transportation, and disposal of a wide variety of radiological and hazardous wastes and materials. Low-level radioactive waste (LLW) is the most volumetrically significant radiological waste stream in the DOE cleanup program, consisting of millions of cubic meters per year.

LLW is defined by exclusion in the United States—that is, it is a residual category for radioactive waste material that is not otherwise categorized—and has no lower or upper activity limits (see Box D-1). As a result, its physical, chemical, and radiological characteristics are extremely diverse. Examples range from lightly contaminated soils and building materials to highly activated nuclear reactor components and sealed sources.

This workshop is charged to explore:

- the key physical, chemical, and radiological characteristics of LLW that govern its safe and secure management (i.e., packaging, transport, storage) and disposal, in aggregate and for individual wastestreams, and

NOTE: An earlier draft of this paper was provided as background material to the workshop participants. The draft was updated and edited after the workshop to produce the document shown in this appendix.

BOX D-1
U.S. Definitions for Nuclear Materials and Wastes

See Box D-2 for summaries of the laws noted below.

Source material:

Defined by the Atomic Energy Act of 1954, as amended (AEA),[a] "The term 'source material' means (1) uranium, thorium, or any other material which is determined by the [Nuclear Regulatory] Commission pursuant to the provisions of section 61 to be source material; or (2) ores containing one or more of the foregoing materials, in such concentration as the Commission may by regulation determine from time to time."

Special nuclear material:

Defined by Section 11 of the AEA;

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

(2) any material artificially enriched by any of the foregoing, but does not include source material."

Spent nuclear fuel:

Defined by Section 2 of the Nuclear Waste Policy Act of 1982[b]; "fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing."

High-level waste (HLW):

Defined by the AEA and the NWPA as amended in 2004;[c]

"(A) the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; and

(B) other highly radioactive material that the Commission, consistent with existing law, determines by rule requires permanent isolation."

Transuranic waste (TRU):

Defined by the Waste Isolation Pilot Plant Land Withdrawal Act;[d] "waste containing more than 100 nanocuries of alpha-emitting transuranic isotopes per gram of waste, with half-lives greater than 20 years, except for:

1) high-level radioactive waste,

2) waste that the Secretary of Energy has determined, with the concurrence of the Administrator of Environmental Protection Agency, does not need the degree of isolation required by the disposal regulations; or

3) waste that the U.S. Nuclear Regulatory Commission has approved for disposal on a case-by-case basis in accordance with the Code of Federal Regulations (CFR), 10 CFR Part 61."

Byproduct material:

From the AEA, Section 11;

"The term 'byproduct material' means—

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

(2) the tailings or wastes produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content;

(3)(A) any discrete source of radium-226 that is produced, extracted, or converted after extraction, before, on, or after the date of enactment of this paragraph for use for a commercial, medical, or research activity; or

(B) any material that—

(i) has been made radioactive by use of a particle accelerator; and

(ii) is produced, extracted, or converted after extraction, before, on, or after the date of enactment of this paragraph for use for a commercial, medical, or research activity; and

(4) any discrete source of naturally occurring radioactive material, other than source material, that—

(A) the Commission, in consultation with the Administrator of the Environmental Protection Agency, the Secretary of Energy, the Secretary of Homeland Security, and the head of any other appropriate Federal agency, determines would pose a threat similar to the threat posed by a discrete source of radium-226 to the public health and safety or the common defense and security; and

(B) before, on, or after the date of enactment of this paragraph is extracted or converted after extraction for use in a commercial, medical, or research activity."

Low-level waste:

The Low-Level Radioactive Waste Act (LLRWPA) of 1980 and the Low-Level Radioactive Waste Amendments Act (LLRWPA amendments) of 1985[e] define LLW as "radioactive material that—

(A) is not high-level radioactive waste, spent nuclear fuel, or byproduct material[f] (as defined in section 11.e (2) of the Atomic Energy Act of 1954…); and

(B) the Nuclear Regulatory Commission, consistent with existing law and in accordance with paragraph (A), classifies as low-level radioactive waste."

This waste classification has no lower or upper activity limits. USNRC 10 CFR 61.2 defines LLW similarly but adds byproduct materials (3) and (4).

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[a]"Atomic Energy Act of 1954, as amended through Public Law 114-92, enacted November 25, 2015," accessed February 24, 2017, https://legcounsel.house.gov/Comps/Atomic%20Energy%20Act%20Of%201954.pdf.

continued

BOX D-1
Continued

[b]"Nuclear Waste Policy Act of 1982," accessed February 24, 2017, http://www.epw.senate.gov/nwpa82.pdf.

[c]"Nuclear Waste Policy Act, as amended, 2004," accessed February 24, 2017, http://www.energy.gov/sites/prod/files/edg/media/nwpa_2004.pdf.

[d]The DOE and USNRC definitions of TRU waste are not consistent.

DOE's definition follows the WIPP Land Withdrawal Act (accessed February 24, 2017, http://www.wipp.energy.gov/library/cra/baselinetool/documents/regulatory%20tools/10%20wipplwa1996.pdf). The USNRC is reviewing its current definition ("Statutory Language and Regulatory History of Commercial Transuranic Waste Disposal," accessed February 24, 2017, https://www.nrc.gov/docs/ML1516/ML15162A828.pdf).

[e]"Low-Level Radioactive Waste Policy Amendments Act of 1985," accessed February 24, 2017, https://www.gpo.gov/fdsys/pkg/STATUTE-99/pdf/STATUTE-99-Pg1842.pdf . Note that the NWPA, as amended 2004, defines LLW differently by adding "transuranic waste" to the list of what LLW is not ("is not high-level radioactive waste, spent nuclear fuel, transuranic waste, or by-product material as defined in section 11.e (2)…").

[f]"[B]yproduct material…as defined in Sec. 11.e (2)" is provided in the Atomic Energy Act of 1954 as amended: "Sec. 11 DEFINITION…e. The term 'byproduct material' means . . . (2) the tailings or wastes produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content…" See "Atomic Energy Act of 1954 as amended by Public Law 114-92, Enacted November 25, 2015," accessed March 1, 2017, https://legcounsel.house.gov/Comps/Atomic%20Energy%20Act%20Of%201954.pdf.

- how key characteristics of LLW are incorporated into standards, orders, and regulations that govern the management and disposal of LLW in the United States and in other major waste-producing countries.

To accomplish this task, case studies will be presented to show how LLW previously without clear or non-optimal disposition pathways have been successfully managed in the United States and internationally. Lessons to be learned from these successes will be highlighted and discussed, particularly with respect to how they can be applied to LLW waste streams that currently lack clear or have potentially non-optimal disposition pathways—referred to as challenging wastes[1] in these proceedings.

The LLW "universe" contains numerous examples of challenging waste streams whose management and disposal pathways do not align directly with the existing U.S. regulatory regime. This workshop will consider waste characteristics, classification, and criteria that have promise for matching

[1]This proceedings refers to LLW without a clear or potentially non-optimal disposition pathway due to their origin, content, or incompatibly with existing regulations and rules as "challenging LLW."

challenging waste streams with appropriate disposition options and could be applied more broadly to other LLW streams in the United States. International classification schemes and case studies will also be presented.

This white paper is intended to inform the workshop discussions and provides background information on the following:

- Entities responsible for the management and disposal of LLW,
- Classification of wastes,
- Current disposal options for LLW,
- Current regulatory landscape for LLW,
- Previous relevant Academies studies, and
- An overview of case studies and challenging LLW.

D.1 ENTITIES RESPONSIBLE FOR THE MANAGEMENT AND DISPOSAL OF LOW-LEVEL WASTE

The main agencies that regulate and oversee LLW disposal in the United States are DOE, the U.S. Nuclear Regulatory Commission (USNRC), and the Environmental Protection Agency (EPA). The states also serve an important role, including regulatory oversight of the four commercially operating LLW disposal facilities in the United States.

The mission of DOE is to safely address the environmental legacy brought about from five decades of nuclear weapons development and government-sponsored nuclear energy research.[2] During the Manhattan Project and the Cold War, LLW was generated through the production and utilization of special nuclear materials, including uranium enrichment, reactor fuel and target fabrication, reactor operations, and plutonium production and recovery. In addition, DOE continues to generate LLW through cleanup activities such as facility decommissioning, tank waste retrieval and immobilization, and soil and groundwater cleanup. This waste is referred to as “government-owned LLW” (previously referred to as “defense LLW”).

DOE manages the largest, most diverse, and technically complex environmental cleanup program in the world. While it has completed the cleanup of more than 90 of the original 108 sites in its cleanup program,[3] the remaining sites present some of the most difficult technical and regulatory challenges—including those posed by the diversity and volumes of LLW. For example, in fiscal year 2015 the DOE complex-wide disposal rate

[2] “Mission and Functions Statement for the Office of Environmental Management,” accessed February 24, 2017, http://energy.gov/em/downloads/mission-functions-statement-office-environmental-management.

[3] A site may still contain radioactive and chemical contamination after cleanup is completed. These sites will continue to be managed by DOE into perpetuity.

for LLW and mixed LLW (MLLW[4]) was 16.67 million cubic feet per year (Marcinowski, 2016).

The USNRC regulates the civilian use of radioactive materials within the United States under the Atomic Energy Act[5] and also has the responsibility to ensure safe and protective disposal of commercial radioactive waste. Commercial LLW is generated through the maintenance and decommissioning of nuclear power facilities, and through industrial, medical, and research activities. The USNRC may relinquish a portion of its regulatory and licensing authority to Agreement States.[6]

The EPA has the authority to set limits on radiation exposure and issue guidelines for radiation protection to federal agencies, including the USNRC and DOE. The EPA also has authority to regulate hazardous chemicals through the Resource Conservation and Recovery Act (RCRA) and the Toxic Substances Control Act (TSCA). MLLW contains hazardous chemicals and is subject to regulation by the EPA and states that host DOE facilities.

LLW is generated in nearly every U.S. state. The Low-Level Radioactive Waste Policy Act of 1980 and its amendment in 1985 (see Box D-2) assigned to each state the responsibility of disposing of its own LLW. Disposal may also be facilitated through state compacts (congressionally ratified agreements among groups of states).

D.2 CLASSIFICATION OF LOW-LEVEL WASTE

LLW is defined by U.S. law, but there is no standard classification system for LLW across federal agencies. For example, DOE identifies requirements for LLW to be disposed of in near-surface disposal facilities using waste acceptance criteria. The USNRC utilizes a classification system based on the content and concentration of specific radionuclides: Class A, B, and C wastes and Greater-than-Class C (GTCC) wastes. Moreover, international regulatory schemes, discussed in a later section, follow a different system.

Most LLW generated in the United States readily aligns with current LLW classification system and regulatory structure. However, some types of LLW were not anticipated or in existence when the classifications,

[4]MLLW is LLW that contains hazardous chemicals.

[5]In addition, the Energy Policy Act 2002 gave the USNRC the authority for regulating discrete sources of radium and accelerator-generated material.

[6]Section 274b of the Atomic Energy Act allows the USNRC to relinquish portions of its Act-derived regulatory authority to states for source materials, byproduct materials, and small quantities of special nuclear materials. An Agreement State has agreed to take responsibility of licensing commercial storage facilities under authority of the USNRC through a written agreement between the state's governor and the USNRC.

BOX D-2
Laws that Govern the Regulation and Management of LLW

1954: Atomic Energy Act (AEA) of 1954, as amended

The AEA requires that civilian uses of nuclear materials and facilities be licensed, and it empowers the USNRC to establish, by rule or order, and to enforce standards to govern these uses. Section 274b of the Act allows the USNRC to relinquish portions of its Act-derived regulatory authority to states for source materials, byproduct materials, and small quantities of special nuclear materials. An amendment to the Act[a] established compensation for, and limits on, licensee liability for injury to off-site persons or damage to property caused by nuclear accidents.

1969: National Environmental Policy Act (NEPA) of 1969, as amended

NEPA requires federal agencies to prepare a detailed environmental impact statement for every major federal action that may significantly affect the quality of the human environment. Such a statement includes a discussion of alternatives to the action and of measures to avoid or minimize any adverse effects of the action.

1982: Nuclear Waste Policy Act (NWPA) of 1982, as amended

The NWPA established statutory definitions for high-level radioactive waste, spent nuclear fuel, and LLW.

1985: Low-Level Radioactive Waste Policy Act (LLRWPA) of 1980, as amended in 1985

The LLRWPA established state (including state compacts) and federal responsibilities for the disposal of commercial LLW, assigned responsibility for managing GTCC wastes to the federal government (DOE EM was later assigned the responsibility), and requires disposal of GTCC LLW at a facility licensed by the USNRC. Recent conclusions and recommendations by USNRC staff for GTCC wastes have been summarized in SECY-15-0094, *Historical and Current Issues Related to Disposal of GTCC LLW* (USNRC, 2015). USNRC staff conducted an analysis of an Agreement State's (specifically Texas') authority to license and regulate the disposal of GTCC, GTCC-like, and TRU waste.[b]

1986: Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) as amended by the Superfund Amendments and Reauthorization Act of 1986

CERCLA authorizes the EPA and state regulators to investigate and remediate sites placed on the National Priorities List;[c] several USNRC-licensed and DOE-managed sites contaminated with radioactive material have been placed on the NPL.

2005: Energy Policy Act (EPAct) of 2005

This Act requires DOE to submit a report to Congress on alternatives for disposing of GTCC LLW. DOE must await action by Congress before issuing a Record of Decision on a preferred disposal alternative.

continued

BOX D-2
Continued

[a]Also known as "The Price-Anderson Amendments Act of 1988," accessed February 24, 2017, http://uscode.house.gov/statutes/pl/100/408.pdf.

[b]"SECY-15-0094: Historical and Current Issues Related to Disposal of Greater-Than-Class C (GTCC) Low-Level Radioactive Waste," accessed February 24, 2017, http://www.nrc.gov/docs/ML1516/ML15162A849.html.

[c]The National Priorities List (NPL) is the list of national priorities among the known releases or threatened releases of hazardous substances, pollutants, or contaminants throughout the United States and its territories. The NPL is intended primarily to guide the EPA in determining which sites warrant further investigation ("Superfund: National Priorities List," accessed February 24, 2017, https://www.epa.gov/superfund/superfund-national-priorities-list-npl).

regulations, and laws were developed and do not readily conform to existing classification systems. Some examples include GTCC and transuranic (TRU) wastes, sealed sources, and incident wastes. Thus, the appropriate disposition pathway and destination for permanent disposal are difficult to plan and the final decisions can be contentious. These and other examples are discussed in a later section.

D.3 CURRENT LOW-LEVEL WASTE DISPOSAL OPTIONS

It is DOE policy to reduce, manage, and dispose of government-owned LLW at its site of generation (i.e., onsite generated LLW) to the extent allowable by site conditions. Government-owned LLW that cannot be disposed of onsite will be disposed of at offsite DOE-managed facilities—except that DOE may also dispose of government-owned LLW in commercial facilities when appropriate for cost reduction or as needed to supplement DOE's capabilities. There are currently six DOE facilities available for the disposal of government-owned LLW: four allow for the storage and disposal of onsite generated LLW, and two allow for disposal of LLW and MLLW generated offsite.

The four DOE sites that allow for disposal of onsite generated LLW are the Idaho National Laboratory; Los Alamos National Laboratory, New Mexico; Oak Ridge Reservation, Tennessee; and Savannah River Site, South Carolina. The other two sites—the Hanford Site near Richland, Washington, and the Nevada National Security Site (NNSS)—allow for disposal of both onsite and offsite generated LLW and MLLW, as long as the waste meets each sites' waste acceptance criteria.[7] In addition, there are two commercial sites that can accept government-owned LLW: EnergySolutions LLW Disposal Facility in Clive, Utah; and Waste Control Specialists (WCS) in Andrews, Texas.

There is currently no disposal capability in the United States for GTCC LLW. However, DOE published the final environmental impact statement for the "Disposal of Greater-Than-Class C (GTCC) Low-Level Radioactive Waste and GTCC-Like Waste" in January 2016 (DOE, 2016);[8] it identifies land disposal at generic facilities and/or the Waste Isolation Pilot Plant (WIPP) as preferred options for the disposal of GTCC LLW and GTCC-like waste.[9]

There are four commercial LLW disposal sites in the United States. They are located in Barnwell, South Carolina, and operated by EnergySolutions; in Clive, Utah, also operated by EnergySolutions; the Hanford site in Washington, operated by U.S. Ecology; and Andrews, Texas, operated by WCS LLC (see Table D-1). Each of these sites is located in an Agreement State and are licensed by their host states under authority provided by the USNRC. Three of the sites (Barnwell, Hanford, and WCS) serve state compacts, and the fourth site (Clive) accepts Class A waste from all U.S. states. The Agreement States determine the types of LLW allowed for disposal in the facilities. Refer to Table D-1 for additional information.

D.4 CURRENT REGULATORY LANDSCAPE FOR LOW-LEVEL WASTE

Several U.S. federal laws govern the regulation and management of LLW; see Box D-2.[10] DOE is self-regulating and implements its responsibilities and authorities for waste management and disposal through directives and orders. These are incorporated into government contracts and enforced through contract and federal oversight (e.g., the Low-level Waste Disposal

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[7] "Disposal Information," accessed February 24, 2017, http://www.hanford.gov/page.cfm/DisposalInformation and "Nevada National Security Site Waste Acceptance Criteria," accessed February 24, 2017, http://www.osti.gov/scitech/servlets/purl/1080356/.

[8] "Greater-Than-Class C Low-Level Radioactive Waste Environmental Impact Statement (GTCC EIS) Documents," accessed February 24, 2017, http://www.gtcceis.anl.gov/documents/index.cfm#final.

[9] "GTCC-like waste" is waste generated or owned by DOE that contains concentrations of radionuclides that are similar to commercially generated GTCC LLW.

[10] See also *Improving the Regulation and Management of Low-Activity Radioactive Wastes* (National Research Council, 2006), for descriptions of other U.S. laws that are not listed in Box D-1 (see Sidebars 2.1 and 2.2, Appendix A, available as https://www.nap.edu/catalog/11595/improving-the-regulation-and-management-of-low-activity-radioactive-wastes [accessed April 9, 2017]).

TABLE D-1 Facilities Available for Commercial LLW Disposal

	Class	Barnwell, SC (EnergySolutions)	Clive, UT (EnergySolutions)	Hanford, WA (U.S. Ecology)	Andrews, TX (WCS)
Types of commercial LLW accepted	**A**	x	x and 11e.(2)	x	x and 11e.(2)
	B	x		x	x
	C	x		x	x
Available to		Atlantic Compact: South Carolina, Connecticut, and New Jersey	All states	Northwest Compact (Alaska, Hawaii, Idaho, Montana, Oregon, Utah, Washington, and Wyoming) and Rocky Mountain Compact (Colorado, Nevada, and New Mexico)	Texas Compact (Texas and Vermont) and other states on a case-by-case basis
Accepts DOE LLW			yes		yes

SOURCE: Data from “USNRC Information Digest, 2016-17,” NUREG-1350, Volume 28, Section 5: Radioactive Waste, accessed February 24, 2017, http://www.nrc.gov/docs/ML1624/ML16245A052.pdf).

Facility Federal Review Group [LFRG]). The directives and orders may be revised over time.

There are two DOE orders that govern radioactive waste management and disposal:

- DOE Order 458.1, *Radiation Protection of the Public and the Environment*, requires DOE to establish requirements to protect the public and the environment against undue risk from radiation associated with radiological activities conducted under the control of DOE.[11]
- DOE Order 435.1, *Radioactive Waste Management*, provides requirements for the management and disposal of HLW, TRU, government-owned LLW, DOE-accelerator produced waste,[12] and the radioactive component of mixed waste.[13]

Under DOE Order 435.1, for instance, a Disposal Authorization Statement (DAS) is required for design and operation of a LLW disposal facility. The DAS consists of a variety of technical documents, including a performance assessment and composite analysis.[14] Waste acceptance criteria are required on a case-by-case basis for each site to meet the order's performance objectives.

The Atomic Energy Act (AEA) (see Box D-2) assigns the USNRC the responsibility for regulating and licensing commercial disposal facilities. The USNRC regulations in 10 CFR Part 61: *Licensing Requirements for Land Disposal of Radioactive Waste* apply to all commercial LLW containing source, special nuclear, or byproduct material (see Box D-1 for definitions) suitable for near-surface land disposal. A subsection within this regulation, Part 61.55,[15] defines three LLW classes from lowest radioactivity levels to highest: Class A, B, and C (see Tables D-2 and D-3). LLW with concen-

[11] "DOE O 458.1, Radiation Protection of the Public and the Environment," accessed February 24, 2017, https://www.directives.doe.gov/directives-documents/400-series/0458.1-BOrder.

[12] "DOE-accelerator produced waste" is radioactive waste produced as a result of operations of DOE accelerators. Accelerator-produced waste is not included in the AEA or NWPA.

[13] "DOE O 435.1 Chg 1, Radioactive Waste Management," accessed February 24, 2017, https://www.directives.doe.gov/directives-documents/400-series/0435.1-BOrder-chg1.

[14] From the "LFRG DOE Order 435.1," accessed February 24, 2017, https://energy.gov/em/lfrg-doe-order-4351, p. IV-12:

> "(3) Composite Analysis: For disposal facilities which received waste after September 26, 1988, a site-specific radiological composite analysis shall be prepared and maintained that accounts for all sources of radioactive material that may be left at the DOE site and may interact with the low-level waste disposal facility, contributing to the dose projected to a hypothetical member of the public from the existing or future disposal facilities."

[15] "USNRC: Part 61.55 Waste Classification," accessed February 24, 2017, https://www.gpo.gov/fdsys/pkg/CFR-2011-title10-vol2/pdf/CFR-2011-title10-vol2-sec61-55.pdf.

TABLE D-2 Near-Surface Disposal for Allowable Concentrations of Long-Lived Radionuclides

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

[a]Units are nanocuries per gram.

TABLE D-3 Allowable Concentrations of Short-Lived Radionuclides for Near-Surface Disposal

	Concentration, (curies per cubic meter)		
Radionuclide	Class A	Class B	Class C
Total of all nuclides with less than 5-year half-life	700	([a])	([a])
H-3	40	([a])	([a])
Co-60	700	([a])	([a])
Ni-63	3.5	70	700
Ni-63 in activated metal	35	700	7000
Sr-90	0.04	150	7000
Cs-137	1	44	4600

[a]There are no limits established for these radionuclides in Class B or C wastes. Practical considerations such as the effects of external radiation and internal heat generation on transportation, handling, and disposal will limit the concentrations for these wastes. These wastes shall be Class B unless the concentrations of other nuclides in Table D-2 determine the waste to be Class C independent of these nuclides.

SOURCE: for Tables D-2 and D-3, "USNRC Part 61.55: Waste Classification," Tables 1 and 2, accessed February 24, 2017, https://www.nrc.gov/reading-rm/doc-collections/cfr/part061/part061-0055.html.

trations of radionuclides that exceed the Class C limits are referred to as GTCC wastes.

Federal laws have assigned three responsibilities to the states related to LLW management and disposal:

- Each state must dispose of LLW generated within its borders, either within the state or through state compacts.
- States may assume portions of the USNRC's regulatory authority for LLW by becoming an Agreement State.
- States regulate non-AEA wastes under authority provided by the state legislature (non-AEA wastes are not covered by federal laws).

The International Atomic Energy Agency (IAEA) issues safety standards to protect health and minimize danger to life and property. The IAEA uses these standards in its own operations, and its member states incorporate these standards in whole or part into their own regulations. The *IAEA Classification of Radioactive Waste—General Safety Guide, No. GSG-1* (IAEA, 2009) presents a scheme for classification and management of radioactive waste based on specific radionuclides, their half-lives, and activity levels in the waste. The standards define six categories of waste (listed here from lowest to highest level of radioactivity):

- exempt waste (EW),
- very short-lived waste (VSLW),
- very low-level waste (VLLW),
- low-level waste (LLW),
- intermediate-level waste (ILW), and
- high-level waste (HLW).[16]

The objective of the IAEA's classification system is to ensure the long-term safety of the public and the environment through the proper management and disposal of the waste. Therefore, the waste is classified according to the degree of containment and isolation required based on the activity content and half-lives of the contained radionuclides.

DOE has previously requested the advice of the National Academies on its waste management programs. *Improving the Regulation and Management of Low-activity Radioactive Wastes* (National Research Council, 2006), funded in part by DOE, is particularly relevant to the current workshop. The report recommended a tiered approach to clarify and simplify

[16]See Figure 1: Conceptual illustration of the waste classification scheme (IAEA, 2009), "Classification of Radioactive Waste," accessed April 9, 2017, http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1419_web.pdf.

the current system for managing low-activity waste[17] by converting it to a risk-informed system. The tiered approach, which identified a set of options in order of increasing complexity, resources, and time, acknowledged that changes to regulations would likely take many years and would require coordination among many federal and state agencies.

The report also found that current laws and regulations for low-activity wastes provide adequate authority for protection of workers and the public (FINDING 1) (see National Research Council, 2006, Appendix A). However, the current system of managing and regulating low-activity waste—as described partially above—is complex (FINDING 2). The report's summary notes that classification systems are becoming more complex as unanticipated waste streams are identified. Indeed, this is one of the motivating factors for the current workshop.

The report further found that certain categories of low-activity wastes have not received consistent regulatory oversight and management (FINDING 3) and that current regulations for low-activity wastes are not based on systematic consideration of risk (FINDING 4). These last two findings pertain primarily to uranium and thorium mill tailings, naturally occurring radioactive material (NORM), and technologically enhanced radioactive material (TENORM). TENORM can contain significant concentrations of radioactive materials. NORM and TENORM wastes are not generally regulated by federal agencies; moreover, their regulation by the states is inconsistent.

The National Academies also published a workshop summary that is relevant to LLW management and disposal: *Best Practices for Risk-Informed Decision Making Regarding Contaminated Sites—Workshop* (National Research Council, 2014), funded by DOE. This workshop explored long-term remediation decisions for contaminated sites based on sustainability principles (balancing between the environmental, societal, and economic goals) rather than purely risk-based or regulation-based approaches.

The National Academies report *Waste Forms Technology and Performance* (National Research Council, 2011) provided guidance on improving current methods for processing radioactive wastes and producing waste forms for disposal. The report found that laws and regulations governing DOE wastes do not establish specific requirements for waste form performance in disposal systems, therefore allowing DOE flexibility in the selection of waste forms.

[17]The 2006 committee intended the term "low-activity waste" (LAW) to be more inclusive than LLW, which has a specific definition through the NWPA. DOE often uses the term LAW to describe lower-activity fractions of tank waste; National Research Council (2006) did not use the term in that sense.

D.5 CASE STUDIES AND EXAMPLES OF CHALLENGING LOW-LEVEL WASTES

The following five case studies will be discussed during the workshop. They represent instances in which an appropriate and acceptable disposal pathway was found for the LLW involved. The presentations on the first day of the workshop will consider these case studies in greater detail, with an eye to drawing lessons for other challenging waste streams for which clear disposal pathways do not currently exist or which are potentially not optimal.

Case Study 1: Separations Process Research Unit Tank Waste Sludge

In the early 1950s, research on plutonium and uranium separation techniques such as PUREX and REDOX[18] was performed at the Knolls Atomic Power Laboratory's[19] (KAPL's) Separation Process Research Unit (SPRU). Radioactive liquid and sludge wastes resulting from the research were stored in seven tanks located onsite. The separations research ended in 1953, and the liquids were retrieved from the tanks in the 1960s, but the sludge wastes remained in the tanks. DOE completed solidification of the sludge and removal of the tanks from KAPL in 2014.[20] The cleanup required coordination among several organizations: DOE, its contractor (URS Corporation), the Office of Naval Reactors (the site's landlord), and WCS. WCS accepted the tank sludge waste and the remediated tanks at its LLW disposal facility in Andrews, Texas.

Case Study 2: Disposal of Low-Level Radioactive Waste at the NNSS

The secure shallow-land burial (to 24 feet [7.3 meters] below ground surface) in the Area 5 Radioactive Waste Management Site at the NNSS accepts LLW, MLLW, and classified waste[21] from more than 25 different sites within the DOE Complex. Per agreement with DOE, Nevada's Division of Environmental Protection (NDEP) participates in the review of waste

[18]REDOX (reduction oxidation) and PUREX (Plutonium and Uranium Recovery by Extraction) are processes for separating plutonium and uranium from irradiated fuel and targets.

[19]The Knolls Atomic Power Laboratory is located in upstate New York. It is a research and development laboratory for the U.S. Navy Nuclear Propulsion Program.

[20]"EM's SPRU Celebrates Waste Removal Success, Safety Milestone," accessed February 24, 2017, http://energy.gov/em/articles/em-s-spru-celebrates-waste-removal-success-safety-milestone.

[21]DOE Order 435.1-1 defines classified waste as "Radioactive waste to which access has been limited for national security reasons and cannot be declassified shall be managed in accordance with the requirements of DOE 5632.1C, *Protection and Control of Safeguards and Security Interests*, and DOE 5633.3B, *Control and Accountability of Nuclear Materials*."

profiles proposed for disposal at the NNSS and in the review of the NNSS Waste Acceptance Criteria.

NDEP's perspectives on the variation in certain key criteria with the broad spectrum of LLW reviewed for disposal at the NNSS will be presented at the workshop, including:

- isotope half-life duration;
- radionuclide activity concentrations as compared to concentrations shown by the existing site performance assessment to meet site performance objectives; and
- plutonium equivalent gram activity.

NDEP will also review general measures that have been taken by DOE, the state of Nevada, and others to address stakeholder concerns associated with transportation and disposal of this LLW.

Case Study 3: Canada: Port Hope Area Initiative

The Port Hope Area Initiative (PHAI)[22] is focused on the cleanup of approximately 1.2 million cubic meters of historic low-level radioactive waste currently stored across sites within the municipality of Port Hope. These wastes, primarily contaminated soil, resulted from radium and uranium refining activities in the 1930s through the 1950s. Construction of a long-term waste management facility (an engineered above-ground mound) is under way. Its location will be within an existing LLW management facility. Waste at the existing site and specified wastes from other sites in Port Hope will be placed in the above-ground mound.[23]

Case Study 4: Canada: Deep Geologic Repository for Low- and Intermediate-Level Waste

Canada does not have an operating disposal facility for low- or intermediate-level wastes (L&ILW).[24] Each waste generator is responsible for

[22]The PHAI Management Office is a tripartite organization involving Atomic Energy of Canada Limited, Natural Resources Canada, and Public Works and Government Services Canada (PWGSC). This office is responsible for carrying out the LLW disposal and cleanup projects in the Port Hope area.

[23]"Port Hope Area Initiative," accessed February 24, 2017, http://www.phai.ca/en/home/default.aspx.

[24]Canadian definitions of low- and intermediate-level wastes are different from U.S. definitions. Current Canadian definitions were adopted in 2008 and are consistent with the IAEA GSG-1 classification system (IAEA, 2009). Canada previously recognized three classes of waste: nuclear fuel waste, uranium mining and milling waste, and low-level waste—the latter defined similarly to the U.S. definition as wastes not included in the first two categories.

the long-term management of their wastes. A new L&ILW disposal facility, a deep geologic repository, in Kincardine (Ontario) is currently undergoing licensing. Ontario Power Generation (OPG), a major Canadian utility and nuclear waste generator, owns and operates the site on which this repository will be built. The repository will be located on an existing nuclear site—the Bruce Nuclear Power Generating Station, adjacent to OPG's Nuclear Waste Management Organization facility. The repository will have a reference depth of 680 meters and has a potential waste capacity totaling approximately 200,000 cubic meters. The municipality of Kincardine is a willing volunteer host for the facility. The hosting agreement specifically excludes the possibility of disposing of used reactor fuel in the facility.

Case Study 5: France: Very LLW and Intermediate LLW Facilities

The management and disposal of LLW in France differs in important ways from approaches used in the United States, even though the waste characteristics are similar in both countries. The French approach considers the physical characteristics of the waste and its hazard, based on half-lives and activities of radionuclides, in determining treatment and disposal options. The French classification makes a distinction between:

- very short-lived, short-lived, and long-lived waste, and
- very low-, low-, intermediate-, or high-level waste (VLL, LL, IL or HL waste).

Approximately 96 percent by volume of nuclear waste in France is VLL and LL short- and long-lived waste and IL short-lived waste. This waste contains less than 0.1 percent of the overall waste activity. Conversely, approximately 4 percent of France's waste by volume is IL long-lived waste and HL short- and long-lived waste containing more than 99.9 percent of the activity.[25]

France has two disposal facilities of relevance to the current workshop. For waste that has a very low-activity level (between 0 and 100 becquerels per gram [Bq/g] or 0 to 2.7 nanocuries per gram [nCi/g]), the waste is managed at the ANDRA CSTFA (Centre de stockage des déchets à très faible activité) disposal facility located in the Aube district, southeast of Paris.[26] This facility has been operational since 2003 and is the first disposal facility in the world for this type of waste. Low- and intermediate-level short-lived

[25] "ANDRA: Waste Classification," accessed February 24, 2017, https://www.andra.fr/international/pages/en/menu21/waste-management/waste-classification-1605.html.

[26] "ANDRA: Very-low-level waste," accessed February 24, 2017, https://www.andra.fr/international/pages/en/menu21/waste-management/waste-classification/very-low-level-waste-1607.html.

waste, such as waste related to maintenance (i.e., clothes, tools, gloves, filters) and the operation of nuclear facilities (i.e., residues from the treatment of gaseous and liquid effluents) has been disposed of at the ANDRA CSFMA (Centre de stockage des déchets à faible et moyenne activité et à vie courte) waste disposal facility since 1992.[27] France currently does not have a facility to dispose of low-level long-lived waste but plans to commission a repository by 2019.[28] Cigéo, a geological disposal facility for intermediate- and high-level and long-lived waste, is expected to be commissioned in 2025.

D.6 CHALLENGING LOW-LEVEL WASTE STREAMS

As noted previously, challenging LLW streams lack clear or have potentially non-optimal disposition pathways. They will be discussed during the breakout sessions on the second day of the workshop.

GTCC and Commercial TRU Waste Exceeding 100 nCi/g

There are three types of GTCC waste considered in DOE's final environmental impact statement analysis (DOE, 2016): Activated metals (generated from the decommissioning of nuclear reactors including core shrouds and core support plate), sealed sources, and other waste (contaminated equipment, debris, scrap metal, filters, resins, soil, and solidified sludge). The combined GTCC LLW and GTCC-like waste inventory is projected to be about 12,000 cubic meters (~420,000 cubic feet) and will contain a total activity of about 160 million curies (MCi); about 75 percent of this waste is commercial GTCC LLW and 25 percent is DOE-owned GTCC-like LLW.[29]

DOE evaluated five alternatives in the final environmental impact statement for the disposal of the GTCC LLW and DOE-owned GTCC-like waste (DOE, 2016). As noted previously, the preferred alternative for the disposal of GTCC LLW and GTCC-like waste is land disposal at generic commercial facilities and/or disposal at the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico.

[27] "ANDRA: Low and intermediate level short-lived waste," February 24, 2017, https://www.andra.fr/international/pages/en/menu21/waste-management/waste-classification/short-lived-low--and-intermediate-level-waste-1609.html.

[28] "ANDRA: Low-level long-lived waste," February 24, 2017, https://www.andra.fr/international/pages/en/menu21/waste-management/waste-classification/low-level-long-lived-waste-1616.html.

[29] "Supplement to Greater-Than-Class C (GTCC) Low-level Radioactive Waste and GTCC-like Waste Inventory Reports," accessed February 24, 2017, http://www.gtcceis.anl.gov/documents/docs/Supplemental-Inventory-Report.pdf.

Sealed Sources

Sealed sources are used in industry, medicine, research, and oil exploration. Some examples include cobalt-60 for medical therapy; cobalt-60 and cesium-137 for bulk irradiation (e.g., medical equipment and food); americium-241/Be for well logging (e.g., for petroleum exploration); and iridium-192 and cobalt-60 for industrial radiography. Disused or unwanted sealed radiation sources range in activity from micro- to kilo-curies; these sources meet USNRC's definition for Class C or GTCC LLW. They can cause acute radiation effects in humans and serious contamination incidents if not managed properly (Cuthbertson et al., 2014).

Clearance or Exempt Waste and Low-Activity Waste

Waste that has very low activity levels is referred to as "clearance" or "exempt" waste by the IAEA (IAEA, 1996). The United States does not have a clearance or exempt classification category. The activity level of this type of waste falls into the lower end of the USNRC Class A designation. This type of LLW may occur in very large volumes. Examples include lightly contaminated wastes generated from decommissioning of nuclear facilities at DOE and civilian sites and from site cleanup activities, including debris, rubble, construction materials, and soils.

Incident Waste

These are wastes resulting from a nuclear incident,[30] for example a severe nuclear accident or nuclear or radiological terrorist attack. Examples of incident wastes include agricultural materials and soils, concrete, asphalt (roads), rubble, debris, metal, activated components, emergency responders' equipment, and cleaning materials. There is potential for very large amounts of waste with low- to high-levels of radioactivity, depending on the type of incident.

Depleted Uranium (DU)

DU waste is a created through the enrichment of uranium, for both commercial and defense applications. DU is unique in its disposal requirements because the activity (and exposure risk) of DU increases with time

[30]Section 11q of the AEA defines a nuclear incident as "any occurrence, including an extraordinary nuclear occurrence, within the United States causing, within or outside the United States, bodily injury, sickness, disease, or death, or loss of or damage to property, or loss of use of property, arising out of or resulting from the radioactive, toxic, explosive, or other hazardous properties of source, special nuclear, or byproduct material."

due to the ingrowth of decay products. Most DU exists as a hexafluoride (DUF_6) and must be converted to DU oxide (e.g., DU_3O_8) for disposal.

Small quantities of DU are currently being disposed of as a Class A waste. However, more than 1 million metric tons (MT) of DU (up to 800 kMT DU at Paducah and Portsmouth and ~300 kMT commercial DU) will require disposal.

There are currently two LLW disposal facilities that are authorized to dispose of uranium oxide: WCS in Texas and the NNSS. A third site, EnergySolutions in Utah, is seeking a permit to authorize disposal of DU in its Class A LLW disposal facility. DOE is currently preparing a supplemental environmental impact statement to analyze the environmental impacts of DU oxide disposition.[31] A USNRC staff review (USNRC, 2008) concluded that existing regulations need to be amended to ensure that commercial DU is disposed of safely.

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[31]To download the Notice of Intent, see "DOE: EIS-0359-S1 AND EIS-0360-S1: Notice of Intent," accessed February 24, 2017, http://energy.gov/nepa/downloads/eis-0359-s1-and-eis-0360-s1-notice-intent.

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Appendix E

Biographies of Panelists and Speakers

LISA EDWARDS is the senior program manager for the Nuclear Chemistry, Radiation Safety and Used Fuel/HLW Management Programs at the Electric Power Research Institute (EPRI). Before joining EPRI in 2006, Ms. Edwards had more than 18 years of experience in commercial nuclear utilities at Duane Arnold, Comanche Peak, Cooper, and St. Lucie. She received her USNRC Senior Reactor Operator license in 2001. She has extensive experience in both solid and liquid radioactive waste processing and management. Ms. Edwards received a B.S. in chemistry from Cornell College, Mount Vernon, Iowa, where she was elected to Phi Beta Kappa and graduated magna cum laude.

MIKLOS (MIKE) GARAMSZEGHY is a chemical/nuclear engineer with more than 35 years of experience in the research, design, and operation and planning of radioactive waste management facilities. He is currently design authority and manager of technology assessment and planning at the Canadian Nuclear Waste Management Organization (NWMO), a utility-owned consortium that has a federal government mandate to develop and implement a program for the long-term management of used nuclear fuel. He has contributed to numerous International Atomic Energy Agency (IAEA), Organisation for Economic Co-operation and Development-Nuclear Energy Agency (OECD-NEA), and International Association for Environmentally Safe Disposal of Radioactive Materials (EDRAM) reports, as well as international peer reviews and projects for more than 30 years, dealing with varied aspects of radioactive waste, advanced fuel cycles, and used nuclear fuel management. He is a past chair of the Canadian Standards

Association N292 technical committee (which deals with radioactive waste standards); current chair of the Canadian Advisory Committee for the ISO TC-85/SC-5 technical committee (which deals with nuclear fuel cycle and waste standards); current Canadian representative on ISO TC85/SC5/WG5 (Waste Characterization); the ISO representative on the IAEA's Waste Safety Standards Committee (WASSC); a member of the Canadian government's External Advisory Panel on Gen-IV reactors; and serves on the technical program advisory boards for several international conferences dealing with radioactive waste management. He holds BASc and MASc degrees in chemical/nuclear engineering from the University of Toronto (Canada) and is a registered professional engineer in Ontario (Canada).

MELANIE PEARSON HURLEY has more than 25 years' experience at the Department of Energy in regulatory compliance and oversight, and program and project management. She has worked in the environmental discipline for the past 35 years in local, state, and federal government agencies. Mrs. Hurley joined the Office of Environmental Management in 2009 after 18 years with the former DOE Office of Environment, Safety and Health (now Environment, Health, Safety and Security). She is currently a headquarters liaison in the Office of Field Operations for the eight Environmental Management Consolidated Business Center Projects. Mrs. Hurley has a B.S. in biology from Virginia Polytechnic Institute and State University and a masters in administration from Central Michigan University.

LAWRENCE "RICK" JACOBI, JR. is the owner and principal consultant at Jacobi Consulting. He is an experienced nuclear industry executive with more than 40 years of front-line experience in project management, licensing, and handling of radioactive material, environmental sciences, legal and regulatory matters, and governmental and media affairs. As a licensed nuclear engineer, health physicist, and member of the State Bar of Texas, Mr. Jacobi provides technical assistance to a variety of nuclear and radiological facilities including waste disposal companies, industrial users, uranium miners, transportation companies, oil and gas exploration and production companies, and investment companies who are seeking an expert opinion on the acquisition of nuclear facilities. He offers hands-on technical assistance in the licensing, construction, operation, and decommissioning of nuclear and radiological facilities, including expert guidance on radiation risk assessment, licensing and permitting of nuclear facilities, environmental assessments, nuclear facility closure and decommissioning plans, radiological and nonradiological environmental monitoring programs, and nuclear facility operating procedures. Mr. Jacobi is an internationally recognized expert on the management of radioactive waste storage, processing, and disposal facilities. He has a B.S. and M.Sc. in nuclear engineering from Texas A&M University and a J.D. from South Texas College of Law.

SCOTT KIRK recently joined BWX Technologies and serves as the director of regulatory affairs for its Technical Service Group. In this capacity, Mr. Kirk provides guidance on a variety of regulatory affairs matters, focusing on radioactive waste management. Prior to his employment with BWX Technologies, Mr. Kirk served as the vice president of licensing and regulatory affairs for Waste Control Specialists during the past 10 years, working on disposal options for complex waste streams such a large quantities of depleted uranium and Greater-Than-Class C low-level waste. Mr. Kirk was also employed by Nuclear Fuel Services and served as the principle liaison with USNRC for more than 10 years. He was responsible for obtaining licensing approval for processing highly enriched uranium for the U.S. Naval Nuclear Propulsion Program and a major nuclear-nonproliferation program for DOE. Mr. Kirk was recently selected by the Southeast Compact Commission for Low-Level Radioactive Waste Management as the recipient of 2017 Richard S. Hodes M.D. Honor Lecture Award for his contributions and innovations in the field of radioactive waste management. He has a M.Sc. in environmental health from East Tennessee State University and a B.S. in geology and physics from Appalachian State University. He is certified in the comprehensive practice of health physics by the American Board of Health Physics.

GREG LOVATO is deputy administrator at the Nevada Division of Environmental Protection (NDEP), where he oversees the Mining, Environmental Cleanup, Waste Management, and Federal Facilities programs. He started his career in at U.S. Environmental Protection Agency (EPA) Region 9 as an environmental engineer working on cleanup, brownfields, and hazardous waste permitting projects in Nevada and California, including 3 years at NDEP in Carson City and 6 years at the Los Angeles Regional Water Quality Control Board. Mr. Lovato holds a B.S. in civil engineering from Stanford University and a B.A. in management-engineering from Claremont McKenna College. Mr. Lovato is a licensed professional engineer (civil) in Nevada and California.

THOMAS E. MAGETTE has more than 30 years' experience managing and conducting nuclear safety, licensing, siting, and environmental assessment programs for energy generation and transmission, national defense, and radioactive waste disposal facilities. He served as the director of the Nuclear Safety Division in DOE's Office of New Production Reactors and was the manager of nuclear programs for the Maryland Power Plant Research Program. His experience covers a wide spectrum of the nuclear industry, including operating reactors, decommissioning, decommissioning funding, transportation, low-level radioactive waste, spent nuclear fuel, and import-export of radioactive material. Mr. Magette currently manages nuclear consulting offerings for PricewaterhouseCoopers (PwC) Capital Projects and Infrastructure in the United States. Mr. Magette holds B.S. and M.S. degrees in nuclear engineering from the University of Tennessee and is a registered professional engineer in Maryland and Virginia.

WILLIAM "WILL" NICHOLS' professional experience as a water resources engineer has focused on hydrology, environmental site characterization, fate and transport modeling, pathway and exposure modeling, uncertainty and sensitivity analysis, integrated risk assessment, probabilistic modeling and simulation, and software quality assurance. He has applied his expertise to help solve problems of national importance in the areas of Resource Conservation and Recovery Act (RCRA) Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), remedial investigations and feasibility studies, radioactive waste disposal facility licensing, National Environmental Policy Act (NEPA) reviews, and environmental impact statement development. Mr. Nichols' expertise has been applied in support of environmental restoration, dose reconstruction for legacy radioactive waste practices, and demonstration of compliance with applicable waste disposal regulatory requirements. He received a B.S. and M.S. from Oregon State University.

ANDREW ORRELL is the section head for Waste and Environmental Safety at the International Atomic Energy Agency (IAEA) where he is responsible for the development and promulgation of internationally accepted standards, requirements, and guides for the safe management of radioactive waste and spent fuel, decommissioning, remediation, and environmental monitoring. In addition, Mr. Orrell oversees the planning and execution of support to the IAEA Member States for the implementation of the IAEA Safety Standards and the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. Prior to joining the IAEA, Mr. Orrell was the director of nuclear energy programs for Sandia National Laboratories. With more than 25 years of professional experience in nuclear fuel cycle and radioactive waste management for the U.S. and several international programs, Mr. Orrell is versed in the complex interdependencies between nuclear energy development, waste management, decommissioning, remediation, and disposal. Mr. Orrell routinely advises government and industry leaders on the technical and policy implications for radioactive waste management, including repository development and licensing, national policy development and regulation, site characterization and safety case development, storage, transportation, and the securing of public confidence.

GÉRALD OUZOUNIAN has been the international director for ANDRA, the French national radioactive waste management agency, since October 2006. Previously, he served as the deputy director for the scientific department at ANDRA for 16 years. He was also in charge of modelling policy and of its implementation in ANDRA. In these functions, he has prepared and implemented studies for low- and intermediate-level activity waste disposal and for used nuclear fuel and high-level waste management, including strategic studies and scientific and technical assessment of the different options. Dr. Ouzounian is a member of the Nuclear Energy Agency's Radioactive Waste Management Committee and the IAEA's Waste Technology Committee. He received a Ph.D. from the Paris University.

DANIEL "DAN" B. SHRUM has worked for EnergySolutions for 19 years. He is the senior vice president for regulatory affairs at EnergySolutions and is responsible for the overall corporate environmental, radiation safety, quality assurance, and security culture, obtaining and updating EnergySolutions numerous permits and licenses, and ensuring that the regulations are followed at all facilities. He has more than 24 years of professional experience including investigations and remedial actions at numerous CERCLA and RCRA sites in Utah, North Dakota, Alaska, and California. Mr. Shrum has designed and installed monitoring well compliance and groundwater extraction systems and has conducted and interpreted aquifer test data for many groundwater investigations. He has successfully managed field teams conducting site characterizations, remedial investigations, and treatability studies. He is experienced in all aspects of drilling and monitoring well completion methods, appropriate air, soil, and groundwater sampling protocol, and quality assurance/quality control procedures. Mr. Shrum has authored or co-authored many soil and groundwater work plans and sampling protocols in addition to investigation reports. Mr. Shrum's academic experience emphasized the geology, hydrogeology, and geochemistry of the several mountain systems in Utah and Idaho.

TEMEKA TAPLIN is the federal program manager for the Off-Site Source Recovery Program within the National Nuclear Security Administration's Office of Radiological Security. During her 5 years of federal service she has worked on numerous radiological security programs dealing with disused, unwanted, and orphaned radiological sources. Under her tenure, thousands of radiological sources have been recovered for final disposition or brought back under regulatory control. She also works with national laboratories and university partners to build educational programs that will increase the number of radiation security experts for the next generation. Ms. Taplin has an M.H.P. and is a graduate of Texas A&M University.

DOUG TONKAY is the director of the Office of Waste Disposal within the Department of Energy's Office of Environmental Management (EM). He manages staff responsible for a portfolio of EM mission activities, including strategic planning and disposal policy for DOE LLW/mixed LLW, a share of the DOE's LLW Federal Review Group, disposition planning for depleted uranium, and planning for Greater-Than-Class C LLW disposition. During his 25-year career at DOE he has worked on a variety of assignments in low-level radioactive waste and transuranic waste management. He also leads the U.S. interagency working group implementing activities for the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management and is also the U.S. country coordinator for two IAEA projects. He earned B.S. and M.Sc. degrees in nuclear engineering from the Pennsylvania State University.

MARK YEAGER is environmental health manager in the Division of Waste Management with the South Carolina Department of Health and Environmental Control. He began his career in 1980 in the Department's Radiological Laboratory while attending the University of South Carolina. In addition to conducting environmental monitoring at the state's various fixed nuclear facilities, Mr. Yeager performed environmental monitoring and sample analyses at the Energy Solutions/Chem-Nuclear Systems LLW disposal facility located in Barnwell, SC. In 1987, Mr. Yeager transferred to the state's Agreement State program as an onsite inspector at the Barnwell facility. He is currently the program's senior health physicist and inspector. Some of his achievements within the field of radioactive waste management and transportation include: contributing member of the Conference of Radiation Control Program Director's (CRCPD's) E-26 Committee on Radioactive Material Transportation; active member and former chairperson of the CRCPD's E-5 Committee on Radioactive Waste Management; providing technical assistance and regulatory oversight to the EPA and U.S. Navy during the radiological decommissioning of the Charleston Naval Shipyard; providing regulatory oversight of the final decommissioning and resulting waste disposal operations of the former Carolinas-Virginia Training Reactor located in Jenkinsville, SC; assisting in the development and subsequent publication of the American National Standard Institute's *Standard N14.36: Measurement of Radiation Levels and Surface Contamination for Packages and Conveyances*; administering the state's transportation inspection program for DOE's Foreign Research Reactor Spent Nuclear Fuel Recovery Program and the Savannah River

Site/Waste Isolation Pilot Plant TRU waste disposal program; assisting in the implementation of the USNRC's initial orders and subsequent security requirements in 10 CFR Part 37 at the Barnwell Disposal Facility; and the Organization of Agreement State's representative on the USNRC's 10 CFR Part 61 Working Group.

Appendix F

Acronyms

AEA	Atomic Energy Act of 1954
ALARA	As low as reasonably achievable
ANDRA	Agence nationale pour la gestion des déchets radioactifs (National Agency for Radioactive Waste Management, France)
ANPR	Advance Notice of Public Rulemaking
BDF	Barnwell Disposal Facility
Bq/g	Becquerels per gram
BTP	U.S. Nuclear Regulatory Commission's *Branch Technical Position on Concentration Averaging and Encapsulation*
BWXT	BWX Technologies, Inc.
CANDU	CANada Deuterium Uranium reactor
CEAA	Canadian Environmental Assessment Agency
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act*, known also as Superfund
CFR	Code of Federal Regulations
CIRES	Centre industriel de regroupement, d'entreposage et de stockage facility (France)
CNSC	Canadian Nuclear Safety Commission
CRCPD	Conference of Radiation Control Program Directors, Inc.
CSA	Centres de stockage de l'Aube (France)
CSFMA	Centre de stockage des déchets à faible et moyenne activité et à vie courte

CSM	Centre [de stockage] de la Manche (France)
CSTFA	Centre de stockage des déchets à très faible activité
DAW	Dry active waste
DHEC	South Carolina Department of Health and Environmental Control
DNFSB	Defense Nuclear Facilities Safety Board
DOE	U.S. Department of Energy
DUF_6	Depleted uranium hexafluoride
DU_3O_8	Depleted uranium oxide
EIS	Environmental impact statement
EPAct	*Energy Policy Act of 2005*
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
g/m^3	Gram per cubic meter
GSG	IAEA General Safety Guide
GSR	IAEA General Safety Requirement
GTCC	Greater-Than-Class C
HEPA	High-efficiency particulate air
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IMPEP	U.S. Nuclear Regulatory Commission's Integrated Materials Performance Evaluation Program
ILW	Intermediate-level waste
KAPL	Knolls Atomic Power Laboratory
L&ILW	Low- and Intermediate-Level Wastes
LANL	Los Alamos National Laboratory
LLRW	Low-level radioactive waste
LLRWMO	Low-Level Radioactive Waste Management Office
LLRWPA	*Low-Level Radioactive Waste Policy Act of 1980*
LLRWPA amendments	*Low-Level Radioactive Waste Policy Act Amendments of 1985*
LLW	Low-level radioactive waste or low-level waste
MARSSIM	U.S. Environmental Protection Agency's *Multi-Agency Radiation Survey and Site Investigation Manual*

MLLW	Mixed low-level waste
MOX	Mixed oxide
mrem/yr	Millirem per year
mSv/yr	Milliseiverts per year
MT	metric ton
nCi/g	Nanocuries per gram
NCRP	National Council on Radiation Protection and Measurements
NDEP	Nevada Division of Environmental Protection
NEPA	National Environmental Policy Act
NNSA	National Nuclear Security Administration
NNSS	Nevada National Security Site
NORM	Naturally occurring radioactive material
NPP	Nuclear power plant
NPV	Net present value
NRC	U.S. Nuclear Regulatory Commission
NWMO	Nuclear Waste Management Organization
NWPA	*Nuclear Waste Policy Act of 1982*
OAS	Organization of Agreement States
OMB	U.S. Office of Management and Budget
OPG	Ontario Power Generation
OSRP	National Nuclear Security Administration's Off-Site Source Recovery Program
PAG	U.S. Environmental Protection Agency's Protective Action Guideline
PE-g	Plutonium equivalent grams
PHAI	Port Hope Area Initiative
PUREX	Plutonium and uranium recovery by extraction
PVP	Property Value Protection
RCRA	*Resource Conservation and Recovery Act*
REDOX	Reduction oxidation process
ROD	Record of decision
RTG	Radioisotope thermoelectric generator
SCATR	U.S. Department of Energy's Source Collection and Threat Reduction (Program)
SECY	Office of the Secretary (of the U.S. Nuclear Regulatory Commission)
SPRU	Separations Process Research Unit

TCLP	Toxicity characteristic leaching procedures
TENORM	Technically enhanced naturally occurring radioactive material
TRU	Transuranic
TSCA	Toxic Substances Control Act
UF	Used fuel
UF_6	Uranium hexafluoride
U_3O_8	Uranium oxide
U.S.	United States
USGS	U.S. Geological Survey
USNRC	U.S. Nuclear Regulatory Commission
VLLW	Very low-level waste
WAC	Waste acceptance criteria
WCS	Waste Control Specialists, LLC
WIPP	Waste Isolation Pilot Plant