LOW-LEVEL RADIOACTIVE WASTE MANAGEMENT AND DISPOSITION: BACKGROUND INFORMATION

DISCUSSION PAPER FOR THE LOW-LEVEL RADIOACTIVE WASTE MANAGEMENT AND DISPOSITION WORKSHOP
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INTRODUCTION

The Department of Energy's Office of Environmental Management (DOE-EM) is responsible for the cleanup of sites used by the federal government for nuclear weapons development and nuclear energy research. DOE-EM "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-EM 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 1: US Definitions for Nuclear Materials and Wastes). 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 waste-streams, and
- 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 disposition pathways have been managed by DOE-EM and its stakeholders and internationally. Lessons to be learned from these successes will be highlighted and discussed how they can be applied to LLW waste streams that currently lack a clear disposition pathway.

Box 1: US Definitions for Nuclear Materials and Wastes

See Box 2 for summaries of the laws noted below.

Source material: defined by the Atomic Energy Act (AEA) as amended 1954,[a] (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 2 of the Nuclear Waste Policy Act (NWPA) of 1982;[b] (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 the NWPA; 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 US 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 Sections 11 e. (1) and (2); any radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing special nuclear material, and (2) the tailings or wastes produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content.

Low-level waste: defined by the NWPA and the Low-level Radioactive Waste Amendments Act (LLWPAA) of 1985;[e] waste that does not meet the statutory definitions for spent nuclear fuel, high-level radioactive waste (HLW), transuranic waste (TRU), or uranium or thorium mill tailings and waste (i.e., Section 11 e. (2) byproduct waste). This waste classification has no lower or upper activity limits.

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[a] http://www.epw.senate.gov/atomic54.pdf (Accessed October 16, 2016)
[b] http://www.epw.senate.gov/nwpa82.pdf (accessed October 16, 2016)
[c] http://www.energy.gov/sites/prod/files/edg/media/nwpa_2004.pdf (Accessed October 16, 2016)
[d] The definition of TRU waste is not entirely consistent between the DOE and the USNRC. DOE follows the WIPP Land Withdrawal Act, as defined in the text above (http://www.wipp.energy.gov/library/cra/baselinetool/documents/regulatory%20tools/10%20wipplwa1996.pdf [Accessed October 16, 2016]). A USNRC discussion on the definition of TRU can be found SECY-15-0094-Enclosure 3: *Statutory Language and Regulatory History of Commercial Transuranic Waste Disposal* (http://www.nrc.gov/docs/ML1516/ML15162A828.pdf [Accessed October 16, 2016]).
[e] https://www.gpo.gov/fdsys/pkg/STATUTE-99/pdf/STATUTE-99-Pg1842.pdf (Accessed October 16, 2016).

The LLW "universe" contains numerous examples of waste streams whose management and disposal pathways do not align directly with the existing US regulatory regime. The regulatory regime may be infeasible or so general as to provide little practical guidance, ability to predict, or excessively expensive or protective requirements in relation to likely risk for challenging waste streams (examples of challenging waste streams are provided in a later section). This workshop will consider waste characteristics, classification, and criteria that have promise for matching challenging waste streams with appropriate permanent disposal 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 safe disposal of LLW in the United States,
- 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.

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-EM, the US Nuclear Regulatory Commission (USNRC), and the Environmental Protection Agency (EPA). The states also serve an important role including regulatory oversight of the four commercial operating low-level disposal facilities in the United States.

The mission of DOE-EM is to safely address the environmental legacy brought about from five decades of nuclear weapons development and government-sponsored nuclear energy research.[1] During the Manhattan Project and the Cold War, LLW was generated through the production and utilization of special nuclear materials by uranium enrichment, reactor fuel and target fabrication, reactor operations, and plutonium production, and recovery. In addition, DOE-EM 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-EM manages one of the largest, most diverse, and technically complex environmental cleanup programs in the world. While it has completed the cleanup of over 90 of the original 108 sites in its cleanup program[2], the remaining sites present some of the most difficult technical and regulatory challenges for the cleanup program—including those posed by the diversity and volumes of LLW. For example, in fiscal year 2015 the DOE complex-wide disposal rate for LLW and mixed LLW (MLLW[3]) was 16.67 million cubic feet (actual).[4]

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 wastes. Commercial LLWs are generated through the maintenance and decommissioning of nuclear power facilities, and through industrial, medical, and research applications. The USNRC may relinquish a portion of its regulatory and licensing authority to *Agreement States*.[6]

[1]http://energy.gov/em/downloads/mission-functions-statement-office-environmental-management (Accessed October 16, 2016).

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

[3]LLW that contains hazardous chemicals, referred to as *mixed LLW*, or MLLW.

[4]http://energy.gov/sites/prod/files/2016/09/f33/Waste%20Disposition%20and%20Transportation.pdf, (accessed October 11, 2016).

[5]In addition, the Energy Policy Act 2002 added certain sources such as discrete sources of radium and accelerator-generated material to the list of civilian sources regulated by the USNRC.

[6]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 commissioner.

The EPA has the authority to set limits on radiation exposure and issue guidelines for radiation protection to federal agencies, including 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 EPA, and states that host DOE facilities.

LLW is generated in nearly every US state. The Low-Level Radioactive Waste Policy Act of 1980 and its amendment in 1985 (see Box 2: Statues and Regulations Relevant to LLW) 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).

CLASSIFICATION OF LOW-LEVEL WASTE

While the United States has defined LLW, there is no standard classification system for LLW across its federal agencies. For example, DOE-EM identifies requirements that allow LLW to be disposed of via near-surface disposal through agreements with stakeholders. The USNRC utilizes a classification system based on the content and concentration of specific radionuclides (e.g., 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 approaches. However, some types of LLW were not anticipated or in existence when the classifications, regulations, and statutes were developed and do not readily conform to existing classification systems. Some examples include GTCC and transuranic (TRU) wastes, sealed sources, and incident wastes. These and other examples are detailed in a later section.

For the purposes of this workshop “challenging LLW” is used to describe a set of wastes that do not align with the existing US regulatory regime. Thus, the appropriate disposition pathway and destination for permanent disposal is difficult to plan and the determination of its disposal pathway can be contentious.

CURRENT LOW-LEVEL WASTE DISPOSAL OPTIONS

It is DOE-EM policy to reduce, manage, and dispose of government-owned LLW at its site of generation (i.e., on-site generated LLW) and to the extent allowable by site conditions. Government-owned LLW that cannot be disposed of on-site will be disposed of at off-site DOE-managed facilities. DOE-EM 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 on-site generated LLW and two allow for disposal of LLW and MLLW generated off-site.

The four DOE sites that allow for disposal of on-site 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 in Washington State and the Nevada

National Security Site (NNSS)—allow for disposal of both on- and off-site 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: U.S. Ecology in Clive, Utah, and Waste Control Specialists (WCS) in Andrews, Texas.

There is currently no disposal capability for GTCC LLW. However, DOE-EM published the Final Environmental Impact Statement for the Disposal of Greater-Than-Class C (GTCC) Low-Level Radioactive Waste and GTCC-Like Waste that identifies land disposal at generic facilities and/or the Waste Isolation Pilot Plant (WIPP) as a preferred alternative for the disposal of GTCC LLW and GTCC-like waste.[8]

There are four commercial LLW disposal sites in the United States. They are located in Barnwell, South Carolina operated by Energy*Solutions*; in Clive, Utah, also operated by Energy*Solutions*; one within the Hanford site near Richland, Washington, operated by U.S. Ecology; and in Andrews, Texas operated by Waste Control Specialists (WCS) LLC (see Table 1). Each of these sites is an Agreement State. Three of the states are part of state compacts and the fourth accepts Class A waste from all US states. These states license the commercial disposal facilities under authority provided by the USNRC. The Agreement States determine the type of LLW allowed for disposal in the facilities. Refer to Table 1 for details of authorization.

TABLE 1: Facilities available for commercial LLW disposal

	Barnwell, South Carolina - Energy*Solutions*	**Clive, Utah - Energy*Solutions***	**Richland, Washington - U.S. Ecology**	**Andrews, Texas - WCS**
Class A	x	x and 11e.(2)	x	x
Class B	x		x	x
Class 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
DOE LLW		yes		yes

SOURCE: data from USNRC Information Digest, 2016-17, NUREG-1350, Volume 28, Section 5: Radioactive Waste (http://www.nrc.gov/docs/ML1624/ML16245A052.pdf, accessed October 14, 2016)

[7] For the Hanford site: http://www.hanford.gov/page.cfm/DisposalInformation and NNSS: http://www.osti.gov/scitech/servlets/purl/1080356/ (both sites accessed October 15, 2016).

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

CURRENT REGULATORY LANDSCAPE FOR LOW-LEVEL WASTE

There are many US federal laws and statutes that govern the regulation and management of LLW; see Box 2 for a timeline of the laws and regulations relevant to LLW.[9]

Box 2: Statues and Regulations Relevant to 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, such standards to govern these uses. Under section 274 of the Act, the USNRC may enter into an agreement with a State for discontinuance of the USNRC's regulatory authority over some materials licensees within the State. A major amendment to the Act 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. The DOE recently completed a final EIS for the disposal of GTCC wastes.

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 responsibility for the disposal of commercial LLW and assigned responsibility for managing GTCC wastes to the Federal Government (DOE EM was later assigned the responsibility) but 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 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.[a]

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

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

2005: Energy Policy Act (EPAct) of 2005

EPAact requires DOE to submit a report to Congress on alternatives under consideration for

[9] See also *Improving the Regulation and Management of Low-Activity Radioactive Wastes* (NRC 2006), for descriptions of other U.S. statutes and laws that are not listed in Box 1 (see Sidebars 2.1 and 2.2, Appendix A, NRC 2006). https://www.nap.edu/catalog/11595/improving-the-regulation-and-management-of-low-activity-radioactive-wastes (accessed October 15, 2016)

disposing of GTCC LLW. DOE must await action by Congress before issuing a Record of Decision on a GTCC disposal alternative.

[a] For more details, see http://www.nrc.gov/docs/ML1516/ML15162A849.html (accessed October 14, 2016).
[b] 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 (https://www.epa.gov/superfund/superfund-national-priorities-list-npl [accessed October 15, 2016]).

The 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 Facility federal Review Group [LFRG]). The directives and orders are incorporated into contracts and may be revised over time, among contracts, or among DOE sites.

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.[10]
- DOE Order 435.1, *Radioactive Waste Management*, provides requirements for the management and disposal of HLW, TRU, government-owned LLW, DOE-accelerator produced waste,[11] and the radioactive component of mixed waste.[12]

For instance, under DOE Order 435.1, 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 the performance assessment and composite analysis. Waste acceptance criteria are required on a case-by-case basis for each site in order to meet the order's performance objectives.

The Atomic Energy Act (AEA) (Box 2: Statues and Regulations Relevant to LLW) gives the USNRC the responsibility for regulating commercial LLW under its authority to license nuclear facilities. The USNRC created several federal regulations that apply to commercial LLW. The regulations stated 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 1 for definitions) suitable for near-surface land disposal. A subsection within this regulation, Part 61.55,[13] defines three LLW classes from lowest radioactivity levels to highest: Class A, B and C (see Tables 2 and 3). LLW with concentrations of radionuclides that exceed the Class C limit are referred to as Greater-than-Class C (GTCC) wastes.

[10] See: https://www.directives.doe.gov/directives-documents/400-series/0458.1-BOrder (accessed October 16, 2016).

[11] Radioactive waste produced as a result of operations of DOE accelerators is considered LLW. It is mentioned specifically since it is not included in the AEA or NWPA (i.e., it is not a byproduct material).

[12] See: https://www.directives.doe.gov/directives-documents/400-series/0435.1-BOrder-chg1 (accessed October 16, 2016).

[13] See: https://www.gpo.gov/fdsys/pkg/CFR-2011-title10-vol2/pdf/CFR-2011-title10-vol2-sec61-55.pdf (accessed October 16, 2016).

TABLE 2: Near-surface disposal for Allowable Concentrations of Long-lived radionuclides

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
Radionuclide Concentration	**(nanocuries per gram)**
Alpha emitting transuranic nuclides with halflife greater than 5 years	100
Pu–241	3,500
Cm–242	20,000

TABLE 3: Allowable Concentrations of Short-lived Radionuclides for Near-Surface Disposal

Allowable Concentrations of Short-lived Radionuclides for Near-Surface Disposal			
Radionuclide Concentration	**curies per cubic meter**		
	Class A	**Class B**	**Class C**
Total of all nuclides with less than 5 year half-life	700	(a)	(a)
H–3 (tritium)	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 2 determine the waste to be Class C independent of these nuclides.

SOURCE for Tables 2 and 3: National Research Council, 2006, Tables A-1 and A-2.

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

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

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).[14]

The basis of the IAEA's classification system is to ensure the long-term safety of the waste. Therefore the waste is classified according to the degree of containment and isolation required to ensure its safety in the long-term. Waste classification parameters are not used to present precise quantitative boundaries between classes of wastes, rather they indicate the severity of the hazard posed by specific waste types.

RELEVANT NATIONAL ACADEMIES STUDIES

DOE-EM has previously requested the advice of the 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-EM, is particularly relevant to the workshop. The report recommended a tiered approach to changing low-activity waste[15] regulations that would clarify and simplify the current system by converting it to a risk-informed system. The tiered approach 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 statutes 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 and 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 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.

[14]See Figure 1: Conceptual illustration of the waste classification scheme (IAEA, 2009), http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1419_web.pdf (accessed October 16, 2016).

[15] The 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; the committee did not use the term in that sense.

The 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-EM. 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 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 rare flexibility in the selection of waste forms.

CASE STUDIES AND EXAMPLES OF CHALLENGING LOW-LEVEL WASTES

The following five case studies will be discussed during the workshop. These examples, summarized briefly here, 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 in greater detail, with an eye to drawing lessons for other *challenging* waste streams for which a clear disposal pathway does not currently exist.

Case Study 1: Separations Process Research Unit (SPRU) tank waste sludge

In the early 1950s, research on plutonium and uranium separation techniques such as PUREX and REDOX[16] was performed at the Knolls Atomic Power Laboratory's[17] (KAPL's) Separation Process Research Unit (SPRU). Radioactive liquid and sludge wastes from the research were stored in seven tanks located on-site. The separations research ended in 1953 and the liquids were retrieved from the tanks in the 1960s, although the sludge wastes remained in the tanks. DOE-EM completed solidification of the sludge and removal of the tanks from KAPL in 2014.[18] The cleanup required coordination with DOE, its contractor (URS Corporation), the Office of Naval Reactors (the site's landlord), and Waste Control Specialists (WCS). WCS accepted the tank sludge waste and the remediated tanks at its LLW disposal facility in Andrews, Texas.

Case Study 2: Low-level Radioactive Waste Streams Reviewed for Disposal at Nevada National Security Site – Key Criteria, Variation, and Management

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

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[16] REDOX and PUREX (Plutonium and Uranium Recovery by Extraction) are processes for separating plutonium and uranium from spent nuclear fuel.

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

[18] See: http://energy.gov/em/articles/em-s-spru-celebrates-waste-removal-success-safety-milestone (accessed October 16,2016).

NDEP's perspective on the variation in certain key criteria with the broad spectrum of LLW reviewed for disposal at NNSS will be presented 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
- and plutonium equivalent gram activity.

A review of general measures that have been taken to address concerns associated with transportation and disposal of this variety of LLW will also be presented.

Case Study 3: Canada: Port Hope Area Initiative
The Port Hope Area Initiative (PHAI)[19] 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 monitoring and maintenance of the new waste management facility (an engineered aboveground mound) is under construction. Its location will be within an existing LLW management facility. Waste at the existing site will be excavated and specified waste from other sites in Port Hope will be placed in the new mound.[20]

Case Study 4: Canada: Deep Geologic Repository for Low- and Intermediate-Level Waste Repository
Canada does not have an operating disposal facility for low- or intermediate-level wastes (L&ILW).[21] Each waste owner is responsible for the long-term management of their waste. A new L&ILW disposal facility 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 deep geologic disposal facility will be built. The repository is located on an existing nuclear site—the Bruce nuclear power generating station, adjacent to OPG's Nuclear Waste Management Organization facility. The new deep geologic repository will have a reference depth of 680 meters and has a potential 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 risk based on half-lives and activities of radionuclides in the waste in determining treatment and disposal options. The French classification makes a distinction between:

- very-short-lived waste, short-lived waste, and long-lived waste, and

[19] The PHAI Management Office is a tripartite organization composed of Atomic Energy of Canada Limited, Natural Resources Canada and Public Works and Government Services Canada (PWGSC) to carry out the low-level waste disposal and cleanup projects in the area.

[20] For more information on the project see Port Hope Area Initiative (for historic LLW) see: http://www.phai.ca/en/home/default.aspx (accessed October 16, 2016).

[21] Canadian definitions of low- and intermediate-levels wastes are different than 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—defined similarly to the US definition as wastes not included in the first two categories.

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

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.[22]

France has two disposal facilities of relevance to the topic of this workshop. For waste that has a very-low-level radioactivity level (between 0 and 100 Becquerels per gram [Bq/g] or 0 to 2.7 nanoCuries per gram [nCi/gm]), 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.[23] 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 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.[24] France currently does not have a facility to dispose of low-level long-lived waste but plans to commission a repository by 2019.[25] Cigeo, a geological disposal facility for intermediate- and high-level and long-lived waste, is expected to be commissioned in 2025.

Challenging LLW Streams

The following forms of LLW do not currently have a clear disposal pathway. They will be discussed during the breakout sessions on the second day of the workshop.

1. Greater-than-Class-C (GTCC) and TRU waste; commercial, activity > 100 nCi/gm

There are three types of GTCC without a disposal pathway: Activated metals (generated from the decommissioning of nuclear reactors including core shroud and core support plate), sealed sources (see above), 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 m^3 (420,000 ft^3) and will contain a total activity of about 160 million curies (MCi) with 75 percent commercial GTCC LLW and 25 percent GTCC-like LLW (DOE owned).

DOE-EM evaluated five alternatives in the Final EIS for the disposal of the GTCC LLRW and DOE-owned GTCC-like waste. 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.[26]

[22] See: https://www.andra.fr/international/pages/en/menu21/waste-management/waste-classification-1605.html (accessed October 15, 2016).

[23] See: https://www.andra.fr/international/pages/en/menu21/waste-management/waste-classification/very-low-level-waste-1607.html (accessed October 16, 2016).

[24] See: https://www.andra.fr/international/pages/en/menu21/waste-management/waste-classification/short-lived-low--and-intermediate-level-waste-1609.html (accessed October 16, 2016).

[25] See: https://www.andra.fr/international/pages/en/menu21/waste-management/waste-classification/low-level-long-lived-waste-1616.html (accessed October 16, 2016).

[26] The Environmental Impact Statement (EIS) is current and projected to include future reactor decommissioning. http://www.gtcceis.anl.gov/ and http://www.nrc.gov/docs/ML1516/ML15162A849.html

2. Sealed sources

Sealed sources are used for industry, medicine, research, and oil exploration. Some examples include Co-60 for medical therapy; Co-60 and Cs-137 to sterilize medical equipment or irradiate bulk quantities of food; Am-241/Be for petroleum exploration; and Ir-192 and Co-60 for structural analysis of buildings and structures.

Disused or unwanted sealed radiation sources range in activity from micro- to kilo-curies, these sources can represent the high-end of materials that meet USNRC's Class C or greater-than-Class-C (GTCC) LLWs. Risks of acute radiation effects in humans and serious contamination incidents should be accounted for.[27]

3. Clearance or exempt waste and Low activity waste (e.g., lowest 10% Class A waste)

Also referred to as "slightly radioactive solid materials", examples include material generated from decommissioning of nuclear facilities at DOE and civilian sites, site cleanup activities such as debris, rubble, construction materials, and lightly contaminated soils.

These LLW fall into the lower end of the USNRC Class A designation (referred to as "clearance" or "exempt" waste in the IAEA waste definitions). This waste has very low activity levels but may arise in very large volumes.

4. Incident waste

These are wastes resulting from a nuclear incident.[28] Examples include soils, concrete, asphalt (roads), rubble, debris, metal, activated components, emergency responders equipment, and cleaning materials. There is potential for very large amounts of wastes with low- to high-levels of radioactivity, depending on the incident.[29]

5. Depleted uranium (DU)

DU is a byproduct of uranium enrichment, both commercial and defense. DU is unique in its disposal requirements because the activity (and exposure risk) of DU increases with time due to the ingrowth of decay products. For disposal, the form of the DU is a depleted uranium oxide (solid). Small quantities of DU are being disposed of as a Class A waste. 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--Waste Control Specialists in Texas and the Nevada Nuclear Security Site. A third site, Energy Solutions 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 (SEIS) to analyze the environmental impacts

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[27] http://www.wmsym.org/archives/2014/papers/14302.pdf

[28] Per AEA Section 11 q, a nuclear incident is: 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.

[29] See: http://www-pub.iaea.org/MTCD/publications/PDF/te_855_web.pdf (accessed October 16, 2016).

of DU oxide disposition. [30] A USNRC staff review concluded that existing regulations need to be amended to ensure that commercial DU is disposed of safely (SECY-08-0147).

[30]The Notice of Intent can be viewed at: http://energy.gov/nepa/downloads/eis-0359-s1-and-eis-0360-s1-notice-intent (accessed October 16, 2016).

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