SAND2015-8502R

Status of DOE-Managed Waste Repository Safety Assessment Information Needs

Fuel Cycle Research & Development

Prepared for
U.S. Department of Energy
Used Fuel Disposition Campaign
David C. Sassani, Laura Price, Robert Rechard,
Ralph Rogers, Emily Stein
(Sandia National Laboratories)

September 30, 2015
FCRD-UFD-2015-000804
SAND2015-XXXX R

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Prepared by:
Sandia National Laboratories
Albuquerque, New Mexico 87185

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U.S. DEPARTMENT OF ENERGY

Sandia National Laboratories

Revision 2
12/20/2012

APPENDIX E
FCT DOCUMENT COVER SHEET [1]

Name/Title of Deliverable/Milestone/Revision No. -- Status of DOE-Managed Waste Repository Safety Assessment Information Needs / M3FT-15SN0824011/ Rev = initial (00)

Work Package Title and Number: DR DOE Managed HLW and SNF Research: Organize information needed for repository design assessments - SNL/ FT-15SN082401

Work Package WBS Number: 1.02.08.24

Responsible Work Package Manager: David Sassani/ David Sassani
(Name/Signature)

Date Submitted: 09/30/2015

Quality Rigor Level for Deliverable/Milestone[2]	☒ QRL-3	☐ QRL-2	☐ QRL-1 Nuclear Data	☐ Lab/Participant QA Program (no additional FCT QA requirements)

This deliverable was prepared in accordance with Sandia National Laboratories
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QA program which meets the requirements of

☒ DOE Order 414.1 ☐ NQA-1-2000 ☐ Other

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Technical Review (TR)
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☐ Signed TR Report or,
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Name and Signature of Reviewers
Geoff Freeze (SNL) Geoff Freeze

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NOTE 2: *In some cases there may be a milestone where an item is being fabricated, maintenance is being performed on a facility, or a document is being issued through a formal document control process where it specifically calls out a formal review of the document. In these cases, documentation (e.g., inspection report, maintenance request, work planning package documentation or the documented review of the issued document through the document control process) of the completion of the activity, along with the Document Cover Sheet, is sufficient to demonstrate achieving the milestone. If QRL 1, 2, or 3 is not assigned, then the Lab / Participant QA Program (no additional FCT QA requirements) box must be checked, and the work is understood to be performed and any deliverable developed in conformance with the respective National Laboratory / Participant, DOE or NNSA-approved QA Program.*

AKNOWLEDGEMENTS

This work was supported by the U.S. Department of Energy Office of Nuclear Energy, through the Office of Used Nuclear Fuel Disposition Research and Development within the Office of Fuel Cycle Technologies.

The authors acknowledge the contributions to this initial activity of the following SNL team members: Carlos Jove-Colon, Yifeng Wang, Christi Leigh, Je-Hun Jang, Paul Mariner, Jeralyn Prouty, Christine Stockman, Mark Rigali, Phil Weck, David Betsill, Eric Lindgren, and Walter Walkow. The authors also acknowledge our gratitude to Peter Swift (SNL), Kevin McMahon (SNL), and Robert MacKinnon (SNL) for discussions on technical aspects and integration of this work. In addition, the authors thank, Joe Price (DOE NE-53), and Tim Gunter (DOE NE-53) for their discussions, oversight and guidance on topics covered in this report.

This report benefitted from internal technical review by Geoff Freeze (Sandia National Laboratories).

CONTENTS

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ACRONYMS and ABBREVIATIONS

BWR	boiling water reactor
DOE	U.S. Department of Energy
DOE-NE	Department of Energy Office of Nuclear Energy
DPC	dual-purpose canister
DWPF	Defense Waste Processing Facility
EBR-II	Experimental Breeder Reactor II
EMT	electrometallurgical treatment
FFTF	Fast Flux Test Facility
HEU	highly enriched uranium
HIP	hot isostatic pressing
HLW	high-level radioactive waste
INL	Idaho National Laboratory
INTEC	Idaho Nuclear Technology and Engineering Center
LEU	low-enriched uranium
LLW	low-level waste
MCO	multicanister overpack
MEU	medium enriched uranium
MOX	mixed oxide (fuel)
PBC	purpose-built canister
PWR	pressurized water reactor
RCRA	Resource Conservation and Recovery Act
SBW	sodium-bearing waste
SMR	small modular reactor
SNF	spent nuclear fuel
SRS	Savannah River Site
U.S.	United States
WIPP	Waste Isolation Pilot Plant
WVDP	West Valley Demonstration Project
WTP	Waste Treatment and Immobilization Plant

Units

ft	foot
GWd	gigawatt-days
in.	inch
lb	pound
MT	metric ton
MTHM	metric ton of heavy metal
MWd	megawatt-days
MTU	metric ton of uranium
wt %	weight percent
W	watt

U.S.ED FUEL DISPOSITION CAMPAIGN/DISPOSAL RESEARCH – STATUS OF DOE-MANAGED WASTE REPOSITORY SAFETY ASSESSMENT INFORMATION NEEDS

1. INTRODUCTION

The U.S. DOE evaluated the need for disposing of only DOE-Managed high-level-waste (HLW, which includes DOE-managed spent nuclear fuel [SNF] in this report) in a geologic repository by using the Nuclear Waste Policy Act 1982 (NWPA, as amended) and stated (DOE, 2015) "A geologic repository for permanent disposal of Defense HLW could be sited, licensed, constructed, and operated more quickly than a Common NWPA Repository and would provide valuable experience to reduce the cost of a future repository and the time needed to develop it." Based in part on that report, the President of the United States issued a memorandum stating that such a repository was required (see website with content at https://www.whitehouse.gov/the-press-office/2015/03/24/presidential-memorandum-disposal-defense-high-level-radioactive-waste-se). This furthered the recommendation from DOE (2014) to "…begin implementation of a phased, adaptive, and consent-based strategy with development of a separate mined repository for some DOE-managed HLW and cooler DOE-managed SNF, potentially including some portion of the inventory of naval SNF." The work in this report summarizes the status of activities within the Used Fuel Disposition Campaign (UFDC) to begin assessing the information needs for evaluating the safety of such a repository, considering both the waste forms being disposed and the repository concepts being considered. This report is milestone M3FT-15SN0824011 performed under the UFDC work package FT-15SN082401 to provide a status of the progress made towards this objective.

1.1 Purpose and Scope

The Waste Form Disposal Options Evaluation Report (SNL 2014) evaluated disposal of both Commercial Spend Nuclear Fuel (CSNF) and DOE-managed HLW and Spent Nuclear Fuel (D-Wastes) in the variety of disposal concepts being evaluated within the Used Fuel Disposition Campaign. The primary goal of this work is to evaluate the information needs for analyzing disposal of solely D-wastes in various geologic mined repository concepts listed below (see Section 2.2). The focus of this status report is to cover the progress made in the end of FY15 toward identifying potential candidate D-Waste types/forms to be added to the list in SNL (2014 – see Table C-1), progress on designing and developing an on-line waste library (OWL) to manage the information of all those wastes (including CSNF if needed), and assessing the information in a manner that allows identification of (and detailed definition of) those characteristics of a D-Waste repository concept that may differ from one that would contain CSNF. The status for each of these three aspects is given in Section 3.

2. Background

The Waste Forms Disposal Options Evaluation report (SNL, 2014) provided part of the technical basis for the DOE (2014) assessment of disposal options. The SNL (2014) work provides the starting point for information consideration of a repository concept for only DOE-managed HLW and SNF disposal. Both the D-Wastes considered in that previous study as well as summaries of the disposal concepts evaluated are given below.

2.1 Waste Types and Waste Forms Considered

The scope of the waste in the Waste Forms Disposal Options Evaluation (SNL, 2014) includes all existing SNF from commercial, defense, and research reactors, and SNF from reasonably foreseeable operations of existing reactors (projected to 2048). That study also includes existing HLW (e.g., vitrified

HLW at Savannah River and West Valley) and waste forms projected to be generated in the future from existing process waste (e.g., projected vitrified HLW from HLW at Hanford, Savannah River and the Idaho National Laboratory). In addition, that study includes consideration of both direct disposal of waste forms that are not currently planned for disposal without further treatment (e.g., calcine waste at the Idaho National Laboratory) and alternatives to planned treatments. That study acknowledges existing plans, commitments, and requirements where applicable, but evaluates options for disposal based primarily on technical, rather than programmatic or regulatory constraints.

The SNL (2014) waste inventory was classified into 43 different "waste types." For the purposes of that study as well as this one, a "waste type" is defined as the currently existing materials (in whatever form, abundance, and location they occupy) that are to be disposed of as at least one, and possibly more than one, waste form in a deep geologic disposal concept (e.g., Hanford tank wastes; commercial spent fuels, HLW glass). A "waste form" is the end-state material as packaged that is to be disposed of in a deep geologic disposal concept. Some "waste types" may have more than one possible alternative "waste form" depending on the processing needed, whereas "waste types" that require no processing other than packaging may equate to a single "waste form."

Considering the alternative treatment options for some of the 43 waste types, SNL (2014) defined 50 waste forms, which were aggregated into the ten "waste groups" (Table ES-2; SNL, 2014) with similar disposal characteristics such as radionuclide inventory, thermal output, physical dimensions, chemical reactivity, packaging of the waste form, and safeguards and security needed for handling, transporting, and disposing of the waste form in the context of the disposal concepts in this study. The aggregation into waste groups allowed a high-level identification of any waste forms that may need to be considered as a separate group due to outstanding qualities in any one of these characteristics. Those same 10 groupings, lacking those solely containing CSNF (WG1 and WG2), are utilized below in this study to consider information needs regarding features of a D-Wastes Repository Concept.

Major assumptions and considerations used in SNL (2014) include the following:

- HLW and SNF considered were restricted to existing materials and those materials that can be reasonably expected to be generated by existing or currently planned facilities and processes.
- The inventory of HLW and SNF was intended to include all existing materials in the U.S. requiring deep geologic isolation, and was based on the best available information.
- Technologies under consideration, including both for waste treatments and disposal concepts, are limited to those that can be deployed in the near future.
- Programmatic constraints, including legal, regulatory, and contractual requirements, were acknowledged where applicable, but were not considered in the technical evaluations, consistent with the goal of the study to provide technical input to strategic decisions. For example, the identification of wastes requiring deep geologic isolation was based on consideration of overall risk, rather than on specific U.S. legal and regulatory requirements.
- Evaluations were primarily qualitative, and are based in large part on insights from past experience in waste management and disposal programs in both the U.S. and other nations.

These assumptions apply also to the present work, which builds off the work done in SNL (2014) but focusses solely on the disposal of DOE-managed High-Level Waste and Spent Nuclear Fuel. As such, the CSNF aspects assessed previously are not included in this consideration. As well, only a subset of the DOE-managed naval SNF (the lower thermal load portion of the waste form) would likely be included in this repository concept (DOE, 2015). This initial work is assessing any needed additions to the D-Wastes to be added to the list compiled previously (see Tables C-1 and ES-1, SNL, 2014), layout the preliminary structure of the on-line waste library (OWL) to manage the waste types/forms information, and develop the information needs for delineating any needed changes to repository concept features relative to a concept that includes CSNF.

The set of disposal concepts used in that evaluation is the same as that identified by DOE's UFDC as a primary target for further research and development. These disposal concepts are presented as a useful and representative, rather than comprehensive, set of concepts, and are also the concepts being used in this work.

2.2 Disposal Concepts Considered

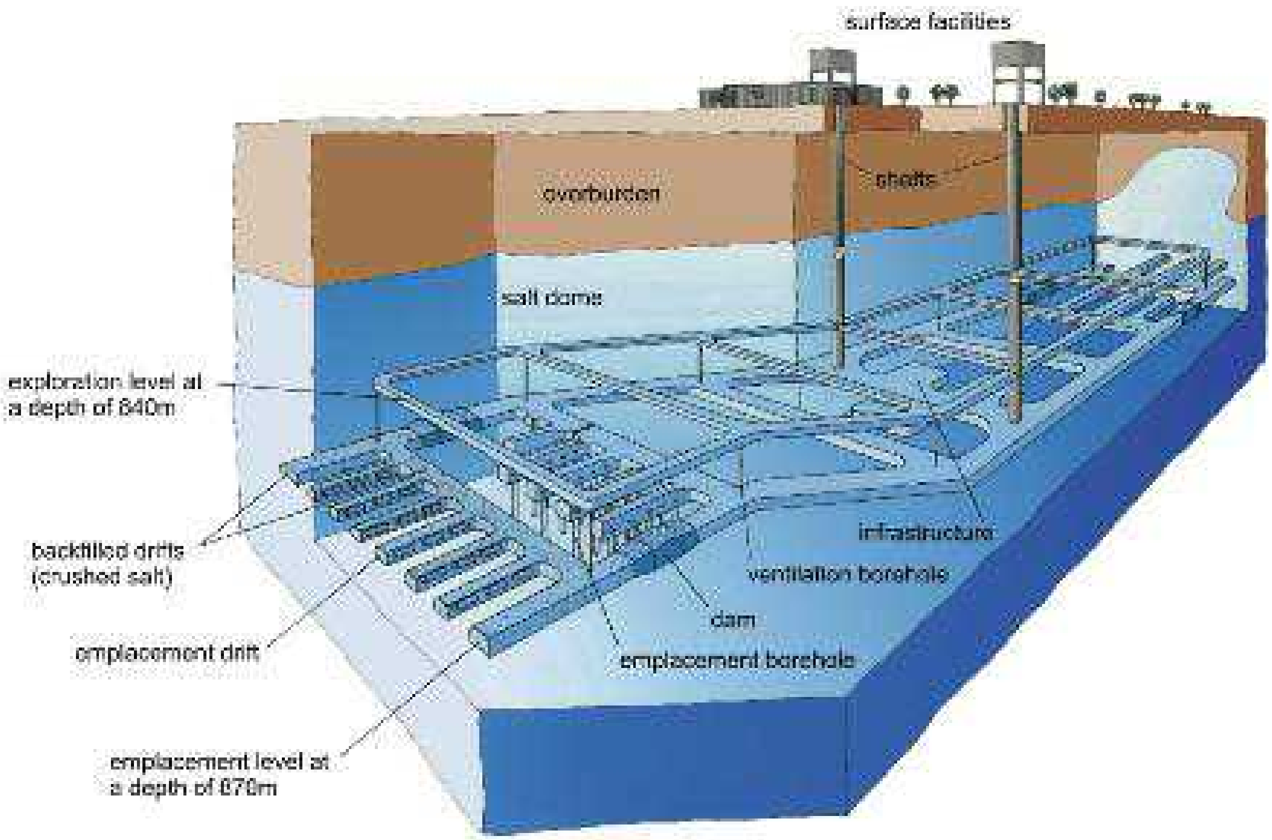
The Waste Forms Disposal Options Evaluation report (SNL, 2014) considers the four representative disposal concepts selected for further research and development activities by the DOE Office of Nuclear Energy's (DOE-NE) UFDC (Rechard et al. 2011). These four concepts are mined repositories in three geologic media—salt, clay/shale rocks, and crystalline (e.g., granitic) rocks—and deep borehole disposal in crystalline rocks. As summarized by Rechard et al. (2011), selection of these four concepts begins with the observation that options for disposal of SNF and HLW have been evaluated in multiple nations for decades, and deep geologic disposal was recognized as early as the late 1950s to be the most promising approach (National Academy of Sciences Committee on Waste Disposal 1957). By the 1980s, the U.S. waste management program had concluded that multiple geologic media had the potential to provide robust isolation, and that conclusion remains valid today. Experience gained in waste management programs in other nations reinforces that conclusion (NWTRB 2009). For example, Sweden and Finland both have license applications pending for proposed mined repositories for SNF in crystalline rock. The U.S. has an operating repository in salt for transuranic (TRU) waste at the WIPP, and Germany has extensive experience with the design of a mined repository for SNF and HLW in salt. France, Switzerland, and Belgium have completed detailed safety assessments for proposed SNF and HLW repositories in clay and shale media. No nations are currently planning deep borehole repositories, but the concept has been evaluated in multiple programs since the 1970s, and remains viable for waste forms small enough for emplacement.

Variants of the four primary concepts are also considered where appropriate. For example, as described by Hardin et al. (2012a), some mined repository concepts can, in principle, be implemented in both open modes (i.e., with active ventilation during the operational period) and closed modes (i.e., with early emplacement of backfill), depending on thermal load management needs.

Other geologic disposal concepts have been proposed and are potentially viable. For example, Canada is currently evaluating a mined repository for intermediate-level radioactive waste in carbonate rocks (NWMO 2011) and the U.S. has evaluated a potential mined repository concept in volcanic tuff (DOE 2008). Although these concepts have unique features that distinguish them from the four selected for consideration within UFDC, attributes of the four concepts discussed here are representative of a broad range of other disposal concepts.

2.2.1 Mined Repositories in Salt

The primary references for mined repositories in salt come from the U.S. WIPP program (DOE 1996b; DOE 2009) which is an operating repository disposing of defense-related transuranic waste, and the proposed German repository at Gorleben (e.g., BMWi 2008). Figure 2-1 shows a representative design for a salt repository. Emplacement of waste would occur in horizontal tunnels (referred to as "drifts" in mining terminology) or in boreholes drilled from drifts at depths between 500 and 1000 meters below the land surface. As proposed, access to the emplacement areas would be by hoists in vertical shafts. Primary isolation would be provided by the essentially impermeable nature of intact salt. Other attributes of salt relevant to repository design and waste disposal include a relatively high thermal conductivity that allows conductive transfer of heat away from the waste, and the plastic creep behavior of salt under pressure that causes it to flow, closing fractures and allowing for seal systems in access shafts that will compact under lithostatic loads to achieve extremely low permeabilities. Bedded salt, which occurs in horizontal layers of nearly pure sodium chloride originally deposited from shallow salt-saturated sea water, can contain both small quantities of trapped brine and interbedded layers of clays and other evaporite minerals such as anhydrite (calcium sulfate). Domal salt, which has moved from its original bedded form into dome-shaped structures due to plastic flow over geologic time, tends to have less water and fewer impurities and interbeds, but also occurs in more restricted geographic settings.



Source: BMWi 2008, Figure 15.

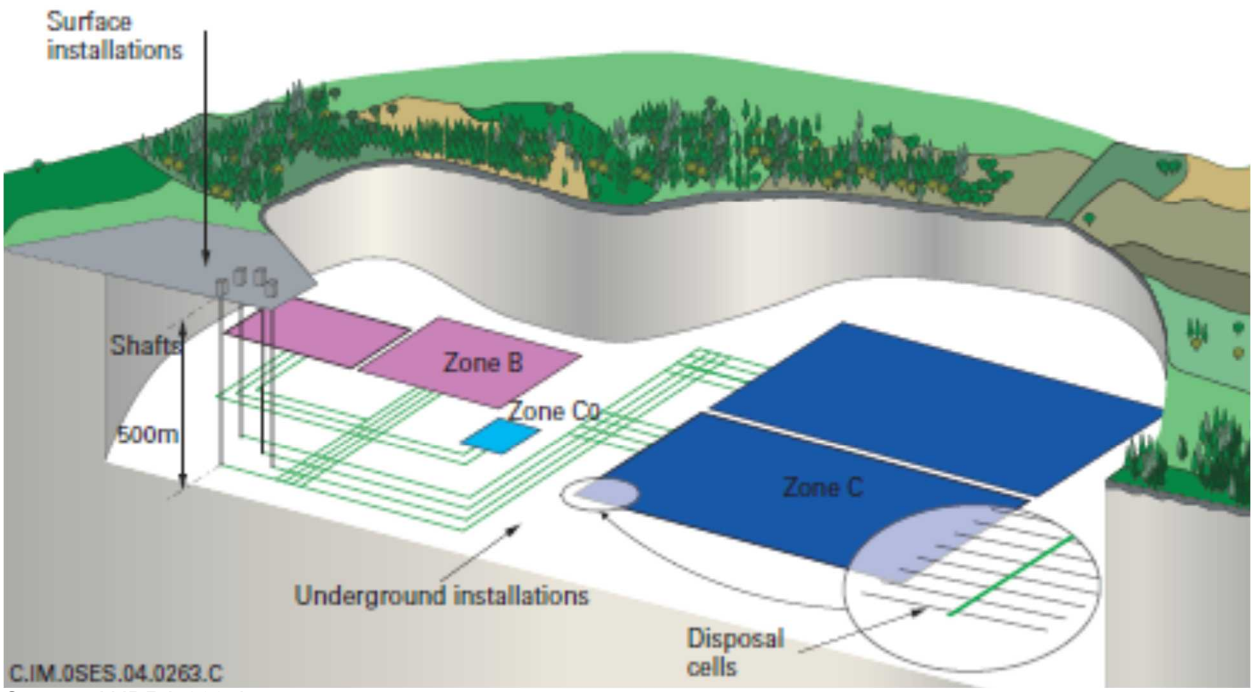
Figure 2-1. Schematic representation of a mined repository in salt

To the extent that sufficient water may be present to saturate the waste emplacement region in salt repositories, it will be a salt-saturated brine and chemical conditions will be reducing, with any free oxygen being consumed by corrosion of metal in the waste packages or other engineered systems. Salt creep will tend to close emplacement regions relatively rapidly (perhaps within decades) after waste emplacement, complicating the implementation of design concepts that call for extended periods of ventilation. However, the relatively high thermal conductivity of salt significantly reduces the need for ventilation to remove heat, compared to other potential media.

Because of the essentially impermeable nature of the host rock and very low potential for advective transport of radionuclides away from the disposal region, salt repository concepts place little or no reliance on the long-term performance of either the waste form or the waste packaging.

2.2.2 Mined Repositories in Clay and Shale Rocks

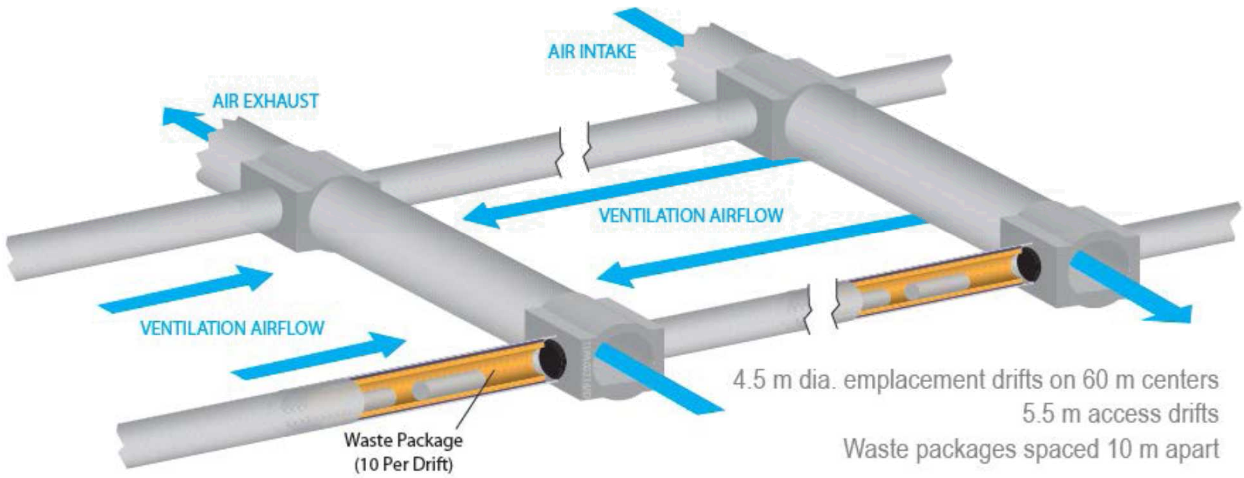
The primary references for mined repositories in clay and shale rocks come from the French, Swiss, and Belgian national programs, each of which is evaluating disposal in argillaceous host rocks (ANDRA 2005a, 2005b; NAGRA 2002; ONDRAF/NIRAS 2011). Figure 2-2 shows a representative design for a mined repository in clay or shale. Emplacement of waste would occur in horizontal holes bored laterally from access drifts at a nominal depth of 500 m below the land surface. As proposed, access to the underground emplacement region would be by hoists in vertical shafts. Isolation would be provided by long-lived waste packages, waste forms that are long-lived in the chemically reducing environment, and by the extremely slow rate of diffusion through the low-permeability host rock. Sorption of radionuclides on clay minerals within backfill and the host rock would effectively prevent long-term releases of all but the most mobile radionuclides, such as ^{129}I and ^{36}Cl, and long-term releases of these species would remain very low.



Source: ANDRA 2005b.

Figure 2-2. Schematic representation of a mined repository in argillaceous rock

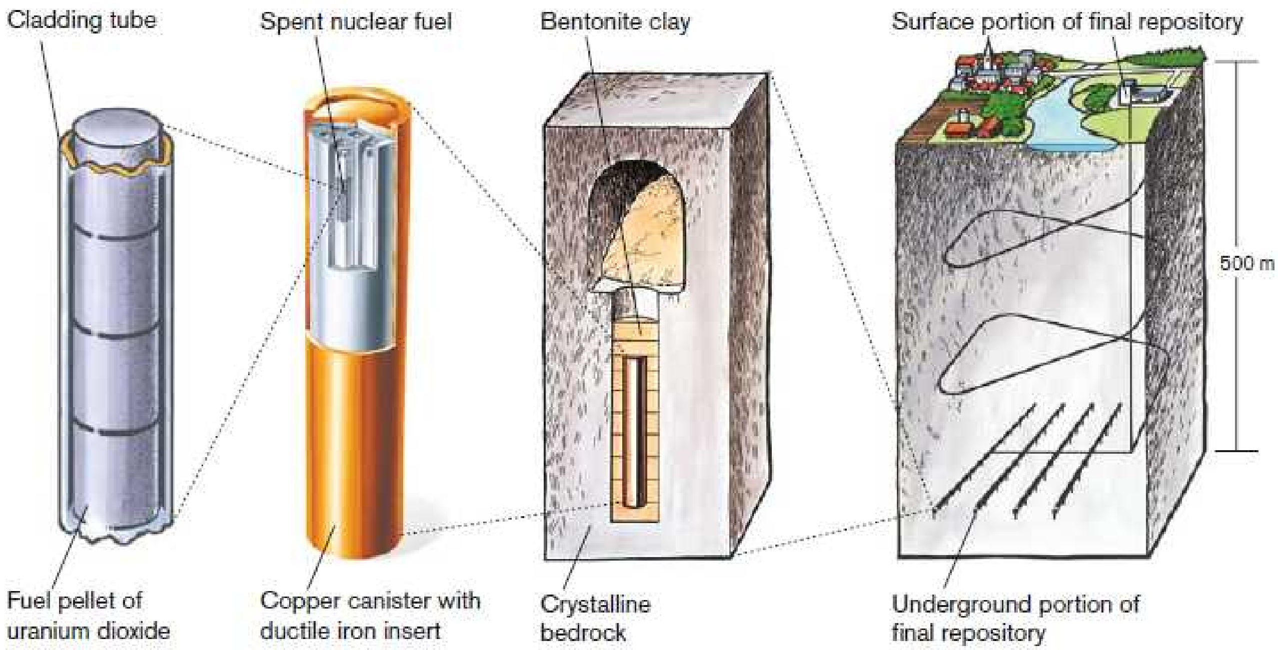
Argillaceous rocks display a broad range of physical properties from weakly indurated clays capable of plastic flow (e.g., the formation being evaluated for disposal in Belgium), to laminated shales common in many sedimentary basins including in the U.S., to strongly indurated and massive argillites such as that being evaluated for disposal in France. All are characterized by extremely low permeability that will lead to diffusion-dominated release pathways and by an abundance of clay minerals that contribute to radionuclide sorption. All also have lower thermal conductivity than salt, and mined repository concepts in clay and shale rocks must be designed accordingly to accommodate thermal loads. The most widely adopted approach to manage decay heat in clay/shale rocks is to use relatively small waste packages (up to 4 spent fuel assemblies per package) and to space the emplacement drifts relatively far apart. Hardin et al. (2012a) evaluated the potential for increasing the thermal loading capacity of a mined repository in shale by considering an "open-emplacement" design concept in which emplacement drifts remain unbackfilled and open to allow extended ventilation to remove decay heat, as illustrated in Figure 2-3. Backfilling and sealing of access drifts occurs at the time of repository closure, with the option of leaving the emplacement drifts unbackfilled permanently if the operational constraints so dictate.



Source: Hardin et al. 2012a, Figure 1.5-3.
Figure 2-3. Schematic of shale unbackfilled open emplacement concept

2.2.3 Mined Repositories in Crystalline Rock

The primary references for mined repositories in crystalline rock come from the Swedish and Finnish programs (SKB 2011; Posiva Oy 2013), which are in the process of seeking licenses to construct and operate facilities for the permanent disposal of SNF. Multiple other nations are also conducting research on mined repositories in crystalline rock, including Canada, Japan, Korea, China, and the Czech Republic. Figure 2-4 shows a representative disposal concept developed for the Swedish program. Wastes (SNF in this example) are emplaced in vertical boreholes drilled in the floor of horizontal drifts at a nominal depth of 500 m below the land surface. Alternative design options call for emplacing waste in horizontal tunnels drilled into the sides of the access drifts. In either case, access to the waste disposal region is by an inclined ramp in this concept, rather than vertical shafts and hoists. Isolation is provided by long-lived corrosion-resistant waste packages (copper in this case, which is thermodynamically stable in the chemically reducing environment), by the durability of the uranium oxide waste form (also stable in reducing conditions) disposed of in the Swedish repository concept, and by the high sorption capability of the bentonite clay buffer that surrounds the waste packages. Other reduced waste forms (e.g., metallic fuels) would be closer to their equilibrium conditions and would corrode more slowly than in oxidizing environments. Still other waste forms (e.g., HLW glass) may not benefit from the reducing environment as much in terms of waste form lifetimes in such a disposal concept, but many radionuclide solubility limits would be very low and substantial performance would be expected based on the waste package lifetime and the bentonite backfill capabilities. Open and interconnected fractures, which can occur in crystalline rocks at these depths, have the potential to provide pathways for advective transport of radionuclides from the repository to the near-surface environment if the near-field barriers are breached, and design concepts therefore call for avoiding emplacement in regions intersected by fractures and for surrounding waste packages with a low-permeability bentonite clay buffer.



Source: SKB 2011, Figure S-1.

Figure 2-4. Schematic representation of a mined repository in crystalline rock

Because bentonite undergoes durable physical changes at elevated temperatures, crystalline repository concepts generally have defined a peak temperature constraint at the waste package surface of approximately 100°C. Existing design concepts meet this constraint with relatively small waste packages, accommodating four spent fuel assemblies per package.

As discussed by Hardin et al. (2012a; 2013), alternative design concepts for mined repositories in crystalline (or other hard) rocks can address thermal load management issues by emplacing waste in large tunnels or vaults that remain open, without backfill, for extended periods of ventilation prior to permanent closure. In unsaturated rocks, above the water table, the limited availability of water for advective transport has the potential to allow permanent disposal without backfill emplacement, although the oxidizing conditions in an unsaturated environment will require alternative designs for waste packaging and will allow for more rapid degradation of UO_2 waste forms. The same would be true for other reduced waste forms, especially metallic waste forms, which would also have higher potential for pyrophoric phenomena. Additionally, the HLW glass waste form may undergo different degradation mechanisms in a humid environment versus saturated conditions (Cunnane et al. 1994). In saturated environments, emplacement of a clay backfill will be desirable after extended ventilation, to reduce the potential for advective transport away from the waste packages.

2.2.4 Deep Borehole Disposal in Crystalline Rock

Deep borehole repositories for permanent isolation of radioactive materials has been proposed and investigated intermittently for decades in the U.S. and other nations (e.g., O'Brien et al. 1979; Halsey et al. 1995; MIT 2003; Nirex 2004; Åhäll 2006; Brady et al. 2009). The earliest proposals for deep borehole disposal considered direct disposal of liquid HLW from reprocessing (National Academy of Sciences Committee on Waste Disposal 1957); subsequent analyses have considered disposal of solid wastes of various types, including glass HLW and surplus weapons-grade plutonium. Published analyses to date have concluded that the overall concept has the potential to offer excellent isolation, but deep borehole disposal of solid wastes has not been implemented in any nation, in part because of the availability of proven mining technologies at the time that national policy decisions were made, and in part because of concerns about the feasibility of retrieving waste from deep boreholes. Advances in drilling technologies over the last several decades (e.g., Beswick 2008) suggest that the construction of deep boreholes should no longer be viewed as a greater technical challenge than deep mines, and that retrieval, if required, should not be viewed *a priori* as unachievable. Retrieval of wastes is likely, however, to remain more difficult from deep boreholes than from most mined repository concepts, and if permanent disposal is not intended, deep boreholes should not be a preferred option.

As described by Arnold et al. (2011; 2012) and illustrated in Figure 2-5, a representative reference design for borehole disposal calls for drilling a borehole to a total depth of approximately 5 km, with at least 3 km of the lowest portion of the hole penetrating crystalline rock. The hole would have a nominal diameter of 0.43 m at depth (requiring larger hole diameters at shallower depth), to accommodate emplacement of waste canisters with maximum external diameters of 0.30 m. Packages would be up to 4.2 m in length. The borehole would be lined with steel casing after drilling, to facilitate emplacement of waste packages vertically in the lower 2 km of the borehole. Following emplacement, casing would be removed from the upper portion of the hole, and seals of alternating sections of concrete and compacted bentonite would be emplaced in the hole.

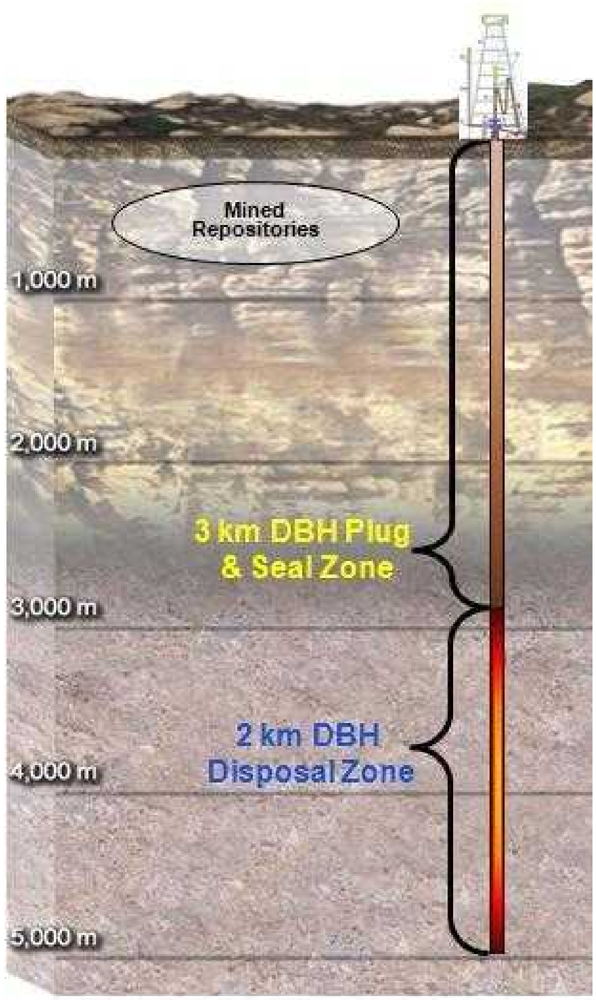


Figure 2-5. Schematic representation of a deep borehole repository

The deep borehole disposal reference design in Arnold et al. (2011) is based on a maximum borehole diameter of 0.43 m (17 in.) at a depth of 5 km because it is expected to be reliably achievable in crystalline basement rocks with currently available, commercial drilling technology. There are no known technical issues that present unreasonable barriers to drilling to this diameter at depth. Land-based drill rigs with the necessary capacity to drill and complete a 17-in. borehole to 5 km depth are commercially available; there are seven companies in the U.S. operating such rigs. Confidence in the ability to drill and complete a borehole decreases with increasing depth and increasing borehole diameter. Future developments in technology may increase capabilities at such depths.

Isolation of the waste would be provided by the extremely low permeability of crystalline rocks at these depths (significantly deeper than the depths proposed for mined repositories), and by the long pathway for diffusive transport upward through the borehole seal system. Low permeability of the host rock and the absence of open fractures would need to be verified through borehole testing before waste was emplaced; testing would also confirm the absence of low-salinity or young groundwater. Because of the primary reliance on the geologic barriers and the long seal system, little long-term performance would be required from the waste packages, which could be constructed of standard drilling-industry steel pipe. The strongly reducing environment in the deep portion of the hole would stabilize reduced redox-sensitive species in the waste and would greatly limit the mobility of many radionuclides because of low radionuclide solubility limits under these geochemical conditions. Other reduced waste forms (e.g., metallic) would be closer to their equilibrium conditions and would corrode more slowly than in oxidizing environments. Still other waste forms (e.g., HLW glass) may not benefit from the reducing environment as much in terms of waste form lifetimes in such a disposal concept, but many radionuclide solubility limits would be very low and substantial performance would be expected the bentonite backfill capabilities.

For the purposes of evaluating a DOE-managed HLW and SNF disposal concept, only the three mined geologic repository concepts in crystalline rocks (e.g., granite), argillite, and salt are going to be considered in detail because the deep borehole concept is currently being considered primarily for a subset of small waste forms, many of which could be disposed in deep boreholes with diameters much less than 17-in, with consideration of potential alternate disposal pathways that allow flexibility for the disposal mission. The work below focuses, in part on assessing those aspects of the mined repositories that may need to be modified in a DOE-managed HLW and SNF only repository relative to the reference cases for those repositories including commercial spent nuclear fuel.

3. Status on Next Stages for Evaluating a DOE-Managed Waste Repository

This section summarizes the progress made in the end of FY15 toward identifying potential candidate D-waste types/forms to be added to the list in SNL (2014 – see Table C-2), progress on designing and developing an on-line waste library (OWL) to manage the information of all those wastes (including CSNF if needed), and assessing the information in a manner that allows identification of (and detailed definition of) those characteristics of a D-waste repository concept that may differ from one that would contain CSNF. The status for each of these three aspects is given below.

3.1 Identifying Potential Additional Waste Types and Waste Forms

Reviewing the materials on radioactive waste types within the DOE-managed realm has produced a number of potential candidates to add to those waste types and waste forms that were evaluated in the Waste Forms Disposal Options Evaluation (SNL, 2014). At this point in time, this all that has been done, with some consideration of the information on these wastes that would be evaluated in the next fiscal year (FY) to fully determine which of such wastes would be added to the list of DOE-managed HLW and SNF to be disposed of in a geologic repository solely for such wastes. A brief summary is given here of the waste types that have been identified.

Within the DOE-managed waste complex, many of the waste types have been included in SNL (2014), as well as their proposed disposition as waste forms. Active research is being performed to evaluate a variety of high level waste glass compositional variations to address limitations on glass formulations due to components such as Fe, Al, Cr, Bi, P, Zr, and S (e.g., Kruger et al., 2012; 2013). In many of these cases, the compositional variation of the glass for some of its elemental components does not appear to warrant a separate tracking as yet because these are still within the R&D stage. One exception in terms of high sulfur waste streams is included below. Additionally, some advanced fuels are being developed that will at some point need disposal dispositioning for research reactors like at the Transient Reactor Test Facility (e.g., Pope et al., 2014). Given the wide range of fuel types considered within the DOE-managed SNF, such advanced fuels will only be considered as they are included into the DOE-managed SNF database as they would provide no immediate substantive difference for consideration. Lastly, many investigations are working to identify candidate waste forms for separated Tc waste streams, either directly from tank waste or from off-gassing as tank wastes are processed into glass (e.g., Westsik et al., 2014). Such forms include a wide variety of solids - borosilicate and iron phosphate glasses, cementitious grouts, geopolymers, phosphate-bonded ceramics, the fluidized bed steam reforming aluminosilicate waste form, the crystalline ceramic Synroc waste form, iron-technetium oxides, metal alloys, technetium oxides, silicate minerals, titanates, sulfides, phosphates, layered double hydroxides, and sulfur-based aerogels. One such waste type/form is included here as it has already been separated and is planned to be formed. Such considerations may suggest additional tracking of potential waste types/forms, however this should only be engaged once the waste types/forms are actually generated.

Potential additions to the SNL (2014) inventory include:

Hanford Tank Waste: Potential Additional Waste Types/Forms

- Existing separated waste
  - Demonstration of Cs-Tc removal from tank waste brines via ion exchange resins to be incorporated into High Activity Waste glass (existing separated waste; Hassan et al., 2000).
- Potential separated waste
  - Potential new glass formulations for projected high sulfur HLW streams from Hanford Tank Waste (likely separated waste; see Kruger et al., 2013).
- Potential separated waste type and waste form
  - WTP LAW vitrification facility off-gas condensate known as WTP Secondary Waste (WTP-SW) will be generated and enriched in volatile components such as ^{137}Cs, ^{129}I, ^{99}Tc, Cl, F, and SO_4 that volatilize at the vitrification temperature of 1150°C in the absence of a continuous cold cap (that could minimize volatilization). The current waste disposal path for the WTP-SW is to process it through the Effluent Treatment Facility (ETF). Fluidized Bed Steam Reforming (FBSR) is being considered for immobilization of the ETF concentrate that would be generated by processing the WTP-SW (Crawford et al., 2014).

3.2 Developing the Online Waste Library (OWL)

Both an overview description of the online waste library (OWL) and a status of defining the approach to developing the OWL are given below.

3.2.1 Description

The online waste library (OWL) would contain information regarding DOE-managed high-level waste (HLW), spent nuclear fuel (SNF), and other wastes that are likely candidates for deep geologic disposal, with links to the current supporting documents for the data (when possible). There may be up to several hundred different DOE-managed wastes that are likely to require deep geologic disposal. The DOE has a database (the Spent Fuel Database) that contains information regarding the SNF that DOE manages. We would not replicate this database and the information in it, but would take advantage of the existing dataset to incorporate it into the on-line waste library. In addition to the data in the Spent Fuel Database, information for each waste listed in the On-line Waste Library could include (except for classified or OUO information):

- Waste Characteristics
  - Narrative description of waste (will have to think about how to handle wastes that have variable processing characteristics, e.g., Savannah River tank waste, some of which has been processed and some of which has not; sodium-bonded fuel, some of which has been treated and some of which has not; Hanford tank waste once treatment starts such that some of it is treated and some is not)
  - Type of waste (HLW or SNF or other (e.g., handled as HLW, TRU?))
  - Origin of waste (commercial, defense, foreign, research, other?)
  - Total quantity of waste (volume and/or mass (as appropriate))
  - Physical form of waste (e.g., rods, plates, powder, liquid, glass)
  - Dimensional characteristic of waste (if a solid waste)
  - Radionuclide inventory and thermal information at specified times (e.g., at inception; at 2015; at 2048)
  - Bulk chemistry of the waste (noting hazardous constituents)
  - RCRA considerations (e.g., not an issue, characteristic, listed)
- Current storage information
  - Current storage location (e.g., INL, Hanford, perhaps more specific?)
  - Description of current storage method (e.g., tanks, canisters, high-integrity canisters, capsules)
  - Number of current containers
  - Dimensions of current storage method (per container, as appropriate)
  - Volume of current storage method (per container, as appropriate)
  - Mass of packaged waste as it currently exists (per container, as appropriate)
  - Radionuclide inventory and thermal information at specified times on a per-container basis (or as available)
  - Current status (e.g., awaiting treatment, awaiting packaging, ready for disposal)
- Planned processing and packaging for final disposition (identify which wastes have baseline processing and packaging plan with a yes/no field. Supply the information listed below for the baseline processing and packaging planned. If alternative processing and/or packaging options exist, provide information listed below for all alternative processing/packaging options)
  - Description of baseline/alternative processing and/or packaging for disposal, including options for processing and/or packaging
  - Number of baseline/alternative packages
  - Dimensions of baseline/alternative package
  - Volume of baseline/alternative package
  - Mass of baseline/alternative package

  - Will baseline/alternative package fit in a deep borehole? (yes/no)
  - Status of baseline/alternative planned processing (e.g., none, in progress, under development)
  - Status of baseline/alternative packaging (e.g., ready, being developed)
  - Radionuclide inventory and thermal information for treated/packaged waste at specified times on a per-package basis (or as available)

- Transportation considerations (e.g., certified transport canister exists (yes/no))
- Current base-line disposition pathway (e.g., deep geologic disposal in repository for HLW and/or SNF, WIPP, TBD)
- Copies of any Records of Decision (RODs) or agreements affecting the waste and its associated plans (linked to the specific data provided)
- Effects of RODs on waste (e.g., date of promised removal from state)
- Responsible contacts currently in charge of the waste types and forms (name, phone number, email address) for storage oversight, for processing, etc.

3.2.2 OWL Status

The OWL has two primary purposes: one purpose, already mentioned, is providing in one place information on the many different DOE-managed wastes that are likely to require deep geologic disposal, such that one can easily query the data. A second purpose is as the primary source for information on the waste types, inventory, and waste form characteristics necessary to develop a database of parameters for a performance assessment (PA) analysis for a safety assessment. The initial focus in this activity will be to develop the database with a user friendly interface and to populate it with the information on waste types and waste forms. Linking OWL directly to performance modeling through a parameter database in order to facilitate PA analysis will occur in subsequent activities after the OWL is fully operational.

Implementing OWL can be viewed in terms of three sub-activities and, thus, three teams: one team to seek out necessary information and develop the metadata for the information, a second team to enter the data in to the database (completing developing metadata, if necessary), and a third team that develops the database and its user interface. Initially, the first two functions are being handled by a single team (Information Team) that is interfacing with the software development team to create a close tie between those who are collecting/analyzing the data and those developing the database (the Development Team). Members of this Information Team have become familiar with the data collected and compiled on waste types/forms in the Waste Forms Disposal Options Evaluation (SNL 2014) as a first step. The Information Team is currently gathering the original source data to serve as a test bed for designing OWL. The next steps for this team include developing a process form of necessary metadata to fully delineate the data details needed prior to entering information into OWL. This team will interface with those identifying the additional possible waste types/forms that are to be considered in addition to those in the SNL (2014) study. The Information Team will meet in October to begin identify sources of information on candidate additional DOE-managed waste types/forms.

The Siting Experience Archive (SEA), which is a database of various experiences primarily in the U.S. on siting large controversial projects, was developed at SNL for DOE in FY13. Although SEA cannot serve as an exact template, SEA has many of the attributes and features required for the implementation of OWL. To facilitate OWL development, the same team that designed the SEA database and interface has been engaged for developing OWL, such that desirable similarities are retained and development of OWL is efficient.

Although the OWL will likely be available through the world wide web, initial development in FY16 will be restricted to internal to SNL until an external interface is needed. Meeting with the Development Team, several basic design parameters were established for OWL. The ability to display various attributes of the information on waste forms was identified as an important function of OWL. The Database Team will spend the beginning of the next fiscal year delineating other important functions based on interactions with the Information Team. The Database Team will also assess the viability of the using inactive and active databases identified by the Information Team. Certainly, attempts will be made to import data from inactive databases, but the extent to which that data will be imported into, rather than accessed through OWL, from currently active databases is unknown at this time. The level of support for active databases will determine the type of arrangements that may be practical. As much as possible, the OWL will leverage existing databases to minimize duplication of effort.

3.3 Integration of Information Needed to Evaluate a Repository for only DOE-Managed HLW and SNF

The conclusion of the Waste Forms Disposal Options Evaluation (SNL 2014) were that

1. the full inventory of DOE-managed and commercial HLW and SNF is diverse, and DOE has a broad range of viable options for disposing of it, and
2. the selection of preferred options will involve policy and programmatic considerations outside the scope of this report, and will be influenced by, and may help inform decisions about, multiple factors that could include future storage and packaging of commercial SNF, treatment and packaging of existing DOE wastes, and progress in repository siting.

All of the disposal concepts evaluated in that study have the potential to provide robust long-term isolation for specific wastes. In addition, each of the three mined repository concepts could accommodate essentially all of the identified waste groups (the only exception was for direct disposal of untreated sodium-bonded SNF, for which information is insufficient to support evaluation for disposal in any geologic disposal concepts). (NOTE that it was also concluded that deep boreholes are feasible for disposal of small waste packages and provide flexibility to any disposal strategy.) Additional generic and site-specific R&D is needed before any disposal options can be implemented, although no recommendations were made with respect to specific R&D activities. The results of the SNL (2014) study indicate that some disposal options form mined repository concepts may provide greater flexibility or fewer challenges than others. Specifically:

a. Salt provides greater flexibility for disposal of heat generating wastes because of the high thermal conductivity and high temperature limit. Disposal in this media provides greater confidence in estimates of long-term performance because it limits radionuclide transport (low permeability) and reduces the reliance on the waste form and waste package lifetimes. The relative lack of water and the high cross-section of chlorine for capture of thermal neutrons make it easier to address criticality concerns. In some cases, it may be appropriate to directly dispose of some untreated waste types, potentially reducing cost and risks associated with waste treatment. The operational experience at the Waste Isolation Pilot Plant provides additional confidence in this disposal concept.
b. Clay/Shale is a disposal media with a significant amount of world-wide experience and it showed strong results as a disposal option for most waste groups with respect to most metrics. It is an attractive disposal option because it limits far-field radionuclide transport (low permeability and high sorption) and, therefore, reduces the reliance on the waste form and waste package lifetimes, compared to a crystalline disposal concept. However, compared to salt, there is more reliance on source-term performance and thermal constraints are greater.

c. Mined repositories in crystalline rocks may offer operational advantages because of the rock strength, which allows robust openings to be easily maintained providing the potential flexibility of possible ramp access. However, for fractured crystalline systems, high reliance on clay barriers immediately surrounding the waste package poses additional challenges for high thermal loads that may degrade such barriers. Because of the need for robust performance of the source-term, confidence in system performance may be directly dependent on very conservative thermal management.

Considering these broad generalities, a first pass at consider the information needs for evaluating the details features of the various mined geologic repository concepts for a disposal system containing only the D-Wastes (i.e., no CSNF and only lower thermal load naval SNF) is summarized below.

3.3.1 Identification of Important Repository Features for Evaluation

DOE-managed HLW and SNF (D-Wastes) differ from CSNF in quantity (there's a lot less) heterogeneity (more so), radionuclide inventory (HLW is weighted toward fission products), thermal load (generally less per waste package), and waste form composition (including the presence of RCRA-regulated wastes, weapons-usable spent naval fuel, and water-soluble salts). DOE-managed HLW and SNF are similar to CSNF in proposed waste package composition (stainless steel) and range of waste package dimensions under consideration. Utilizing the detailed information on waste forms included within the Appendices of SNL (2014), considerations of these parametric aspects helps define the data characteristics that would be most central to evaluating the potential changes to features of the repository concept. Our preliminary assessment is as follows:

Quantity: The inventory of commercial SNF in 2048 under the "no replacement scenario" (Carter et al., 2013) is projected to be 142,000 MTHM or 183,896 m^3. The projected DOE-managed HLW inventory is on the order of 26,000 m^3 (actual volume depends on treatment methods) and the projected DOE-managed SNF inventory is 2532 MTHM.

Heterogeneity: Commercial SNF consists of Low Enriched Uranium (LEU) UO_2 plus some amount of mixed oxide fuels. Though variations exist in assembly and cladding materials, initial enrichment, and discharge burnup, the CSNF waste stream is relatively homogeneous compared to the DOE-managed waste stream, which contains both high-level waste and spent fuel. DOE high-level waste forms potentially include glass and ceramic waste forms, water-soluble salts, and metals. DOE-managed SNF includes LEU, Moderate EU, and High EU waste forms including metals, UO_2, MOX, Th/U oxides, and Th/U carbides.

Radionuclide Inventory: Radioactivity in CSNF comes in almost equal amounts from transuranic isotopes (mainly ^{241}Pu, ^{238}Pu and ^{241}Am) and fission products (^{137}Cs, ^{90}Sr and their daughters). Radioactivity in some DOE waste streams (i.e., Cs and Sr capsules and calcine waste) comes almost entirely from ^{137}Cs, ^{90}Sr and their daughters. Other DOE waste streams, though dominated by ^{137}Cs and ^{90}Sr, contain enough transuranic isotopes that these isotopes would remain important to PA (e.g., spent naval fuel, Na-bearing waste).

Thermal Load: The D-Wastes with the greatest thermal load are Cs and Sr capsules (up to ~1.6kW/waste package using 2007 decay inventory), Electrometalurgically Treated (EMT) salt waste (~2.4 kW/waste package for 6-yr-old waste), and spent naval fuel (average 4.25 kW/waste package). All of these produce less heat than CSNF in any of its potential packaging (~10-100 kW/waste package directly out of the reactor), though only the lower thermal load naval Spent Fuel would likely be disposed of in a D-Wastes repository system.

Waste Forms: Some DOE-managed waste forms can be expected to degrade more quickly than CSNF (e.g., untreated calcine waste and other salts, and the small, reactive wastes included in WG5). Soluble halide-containing salts have the potential to create a corrosive repository environment and adversely affect the performance of adjacent waste packages. Several high-level waste streams contain RCRA-regulated wastes (including the tank waste at Hanford, calcine waste, Na-bearing waste, and Cs and Sr capsules); whether final waste forms will be governed by RCRA depends in some cases on how the waste is processed. Some of the naval SNF is as much as 93-97 wt % ^{235}U. DOE-managed SNF and the high-level salt waste resulting from EMT of Na-bonded SNF contain enough fissile material that criticality needs to be considered and/or managed.

Waste Package: Proposed waste package dimensions for most DOE waste forms are 2’x10’ or 2’x15’ (diameter x length), comparable to dimensions of small purpose-built waste package for CSNF. Proposed waste packages for HIP calcine and existing packages for naval SNF are larger, comparable in size to Dual Purpose Containers for CSNF. Most waste package materials under consideration are stainless steel.

Natural System Considerations: The Waste Forms Disposal Options Evaluation (SNL, 2014) concluded that any of the repository disposal options (salt, clay, or crystalline) could successfully isolate DOE-managed waste, but noted advantages and disadvantages, including: disposing of corrosive (salt) waste forms in a salt repository eliminates concern about the effects of corrosion on adjacent waste packages, because the salt repository concept does not rely upon waste package performance for isolation of waste. A salt repository is advantageous for waste with high fissile content, because the high concentration of neutron-absorbing ^{36}Cl in repository porewater/host rock can prevent criticality. Waste forms containing soluble Pu (e.g., untreated salt-waste from EMT of Na-bonded SNF) may require extra care if disposed of in a crystalline repository due to the potential for colloidal transport in fractures.

Design Features/General: A repository for DOE-managed waste would be smaller than a CSNF repository due to smaller waste volume (only about 1/6). The lower thermal load of DOE-managed waste would potentially allow closer waste package and/or drift spacing, further reducing the repository footprint. Because radionuclide inventory is weighted more heavily toward short-lived fission products (than CSNF), the time over which post-closure safety must be assured may be shorter than for a CSNF repository, but this would depend on the external regulatory framework. The presence of corrosion-causing and highly soluble waste forms (salts), excess fissile material, and RCRA wastes may create concerns specific to a D-Waste repository.

These considerations lead directly to the need to define those Features, Events, and Processes (FEPs) that would be handled substantively differently for a D-Wastes Repository concept versus one that included CSNF. Because of the various reliance on engineered (most for crystalline/granite repository concepts and least for salt repository concepts), the list of altered FEPs could be different depending on the specific geologic disposal system being evaluated. The FEPs process allows for direct linkage to those aspects of the disposal option (combined waste forms and repository concept) that need to be explicitly evaluated for a D-Wastes repository. The initial activities in this area next FY would be to define the set of FEPs that appear affected, then to develop the revised evaluations of those, as well as the changes needed to the concepts for the disposal system.

4. Objectives for Future Work

The above status provides the results of about one month’s effort in FY15 on the initial assessment for identifying the potential additional DOE-managed wastes, the preliminary definition of the on-line waste library (OWL) to manage detailed data and information sources for those wastes, and preliminary considerations on information needs for assessing the postclosure performance and safety of various D-Waste repository concepts. These effort will continue in FY16, with the emphasis on the development, implementation, and population of the OWL, as well as with the addition of a fourth activity to assess and define the waste form performance constraints in more detail of the variety of D-Wastes for use within safety assessments of each D-Wastes repository concept.

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