SAND2015-9947C

Logistics Modeling of Emplacement Rate and Duration of Operations for Generic Geologic Repository Concepts - 16529

Elena Kalinina and Ernest Hardin

Sandia National Laboratories, P.O. Box 5800, MS 0779, Albuquerque, NM 87185-0779
eakalin@sandia.gov

ABSTRACT

This study (1) identified potential geologic repository concepts for disposal of spent nuclear fuel (SNF) and (2) evaluated the achievable repository waste emplacement rate and the time required to complete the disposal for these concepts. Total repository capacity is assumed to be approximately 140,000 MT of spent fuel. The results of this study provide an important input for the rough-order-of-magnitude (ROM) disposal cost analysis.

The disposal concepts cover three major categories of host geologic media: crystalline or hard rock, salt, and argillaceous rock. Four waste package sizes are considered: 4PWR/9BWR; 12PWR/21BWR; 21PWR/44BWR, and dual purpose canisters (DPCs). The DPC concepts assume that the existing canisters will be sealed into disposal overpacks for direct disposal. Each concept assumes one of the following emplacement power limits for either emplacement or repository closure: 1.7 kW; 2.2 kW; 5.5 kW; 10 kW; 11.5 kW, and 18 kW.

To estimate the repository emplacement rate and duration of operations, the logistics simulations were performed assuming the following conditions:

- An interim storage facility (ISF) becomes operational in 2021 and accepts SNF in DPCs from the reactor sites at the rate of 3,000 MTU per year.
- DPCs are accepted and stored at the ISF until the repository begins accepting waste in 2048 at the rate of 3,000 MTU per year.
- DPCs are repackaged at the repository into waste packages of the specified size, except for cases in which the DPCs are directly disposed of.
- The waste packages (including DPCs) are emplaced into the repository as soon as their thermal output is at or below the specified emplacement power limit.

The logistic simulation demonstrated that all the scenarios, except the one with the emplacement power limit of 1.7 kW and the waste package size of 12PWR/21BWR, are very similar with regard to the emplacement rates and duration of operations. The emplacement rate goal of 3,000 MTU per year can be maintained (or nearly so) from 2048 until 2092. Most of the inventory (99%) can be emplaced during the 45 to 54 years of repository operations. The remaining 1% of the inventory (1,400 MTU) requires some additional emplacement time or smaller waste packages.

The emplacement rate in the scenario with the emplacement power limit of 1.7 kW and the waste package size of 12PWR/21BWR varies from 500 to 1,800 MTU per year during the first 170 years of operations and drops significantly after that.

Emplacing 99% of the inventory requires 197 years. The duration of operations can be significantly reduced if 50% or more of SNF inventory is emplaced in 4-PWR/9-BWR waste packages.

Estimating the ROM disposal cost was not an objective of this analysis. However, an example of potential disposal costs is provided to demonstrate the differences between the a few repository concepts.

INTRODUCTION

The cost of a geologic repository is a significant part of the radioactive waste management system. The disposal cost will depend on the type of geologic media, waste package capacities, waste emplacement rates, and many other factors. This study provides an important input for the rough-order-of-magnitude (ROM) disposal cost analysis.

First, sixteen potential geologic repository concepts for disposal of spent nuclear fuel (SNF) were identified. An extensive knowledge base accumulated by the international projects [1, 2, 3, and 4] was used when applicable. The disposal concepts cover three major categories of host geologic media; four waste package sizes; and 6 emplacement power limits for either emplacement or repository closure. The resulting repository concepts are summarized in Table I.

TABLE I. Summary of Potential Geologic Repository Concepts

Geologic Medium	Waste Package Capacity	Concept ID	Emplacement Thermal Power Limit (kW)	Repository Closure Thermal Power Limit (kW)
Crystalline (enclosed)	4PWR/9BWR	Concept 1	1.7	*
Argillaceous (enclosed)	4PWR/9BWR	Concept 2	1.7	*
	12PWR/21BWR	Concept 3	1.7	*
Salt (enclosed)	4PWR/9BWR	Concept 4	2.2	*
	12PWR/21BWR	Concept 5	5.5	*
	21PWR/44BWR	Concept 6	10	*
	DPC	Concept 7	11.5	*
Hard rock unsaturated (open)	12PWR/21BWR	Concept 8	10	4
	21PWR/44BWR	Concept 9	18	7
	DPC	Concept 10	18	7
Hard rock saturated (open)	12PWR/21BWR	Concept 11	10	2
	21PWR/44BWR	Concept 12	18	3
	DPC	Concept 13	18	3
Argillaceous (open)	12PWR/21BWR	Concept 14	10	3
	21PWR/44BWR	Concept 15	18	3
	DPC	Concept 16	18	3
* These concepts are backfilled at emplacement.				

The DPC concepts assume that the existing canisters will be sealed into disposal overpacks for direct disposal.

The distinction between enclosed and open emplacement modes relates to whether engineered or natural backfill/buffer material is placed in contact with the waste packages at emplacement. This condition is important for thermal analysis because it distinguishes the need for a separate thermal power limit for open-mode repository closure, in addition to the limit for emplacement. All concepts assume the saturated conditions, except concepts 8, 9, and 10.

Next, the achievable repository waste emplacement rate and the time required to complete the disposal for the identified disposal concepts were evaluated based on the logistics simulations. Total repository capacity was assumed to be approximately 140,000 MT of spent fuel.

Note that the logistic simulations account for the emplacement power limit and the waste package size only. As a result, 16 different disposal concepts could be simulated with nine scenarios. For example, Concept 1(crystalline enclosed) and Concept 2 (argillaceous enclosed) can be grouped because they have same emplacement power limit (1.7 kW) and same waste package size (4PWR/9/BWR). However, these concepts are not identical with regard to disposal cost.

APPROACH

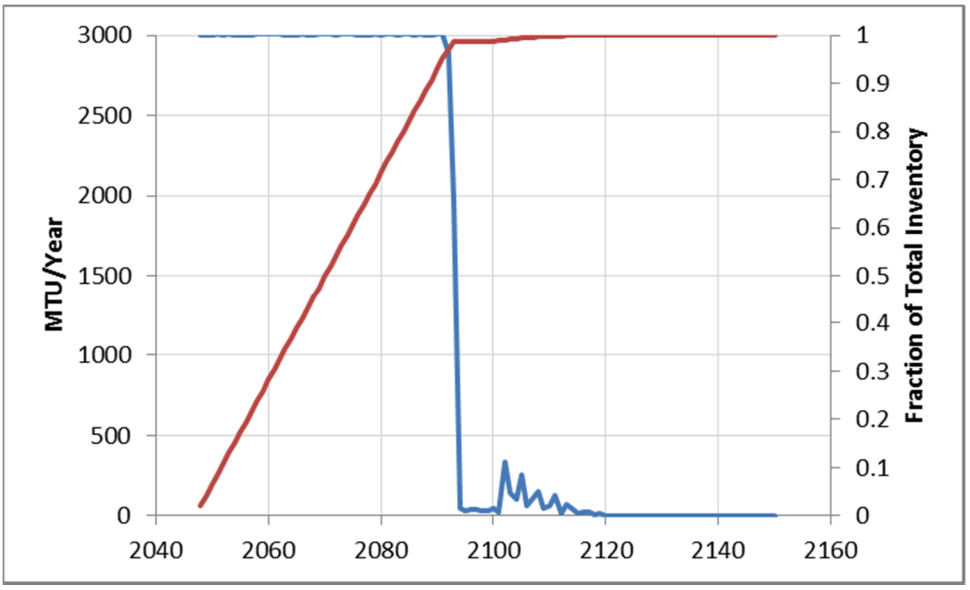
The logistical simulation code TSL-CALVIN [5] was used to simulate the SNF management system including waste emplacement. The logistics simulation model was set up to assume the following conditions:

- SNF is loaded into DPCs of the size now in use at operating reactor sites to keep pool inventory at or below maximum capacity.
- SNF from pools is loaded into DPCs of the size now in use starting 5 years after reactor shutdown.
- An interim storage facility (ISF) for commercial SNF becomes operational in 2021 and accepts waste from the reactor sites at the rate of 3,000 MTU per year.
- DPCs that meet the associated transportation power limits are transported from reactor sites to the ISF until all the reactor sites are unloaded.
- DPCs are stored at the ISF until the repository begins accepting waste in 2048 at the rate of 3,000 MTU per year.
- DPCs are transported to the repository where they are repackaged into waste packages of a specified size, except for the DPC direct disposal case. No repackaging is done in the DPC direct disposal case.
- The waste packages (or DPCs) are emplaced in the repository as soon as their thermal output is at or below the specified emplacement power limit.
- Waste packages are loaded using a blending algorithm in which cooler assemblies are mixed with hotter assemblies to achieve desired thermal output.

The focus of this analysis was on the achievable emplacement rates and the duration of repository operation. The results are discussed in the following section.

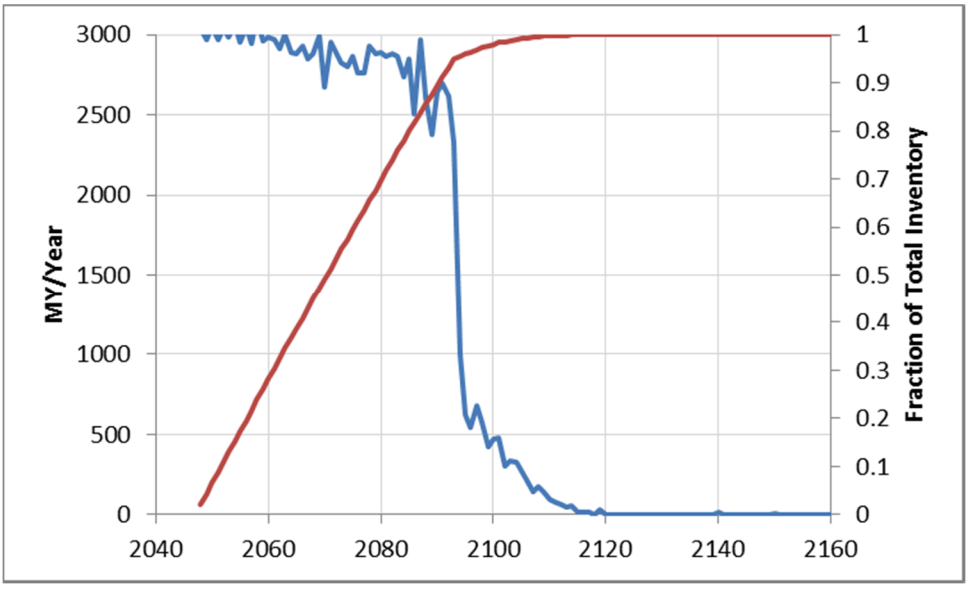
DISCUSSION OF RESULTS

Emplacement rates for each year (blue curves), and cumulative fractions of total inventory disposed of (red curves), are shown as functions of time in Fig. 1(Concepts 1 and 2) and Fig. 2 (Concept 7). The results for the other concepts, except Concept 3, are very similar to the ones shown in Fig. 1.



Blue curve: annual rate. Red curve: cumulative rate.

Fig. 1. Emplacement Rates for Disposal Concepts 1 and 2 (4PWR/9BWR, 1.7 kW).



Blue curve: annual rate. Red curve: cumulative rate.

Fig. 2. Emplacement Rates for Disposal Concept 7 (DPCs, 11.5kW).

Most of the disposal concepts are very similar with regard to emplacement rates and duration of disposal operation. Emplacement rate of 3,000 MTU/year can be maintained from repository opening in 2048 until at least 2092. A total of 99% of SNF inventory can be emplaced during 45 to 54 years of the repository operations. The remaining 1% of the inventory (1,400 MTU) requires some additional emplacement time or a different (smaller) waste package.

The direct disposal of DPCs in Concept 7 (Fig. 2) takes slightly longer time and results in lower emplacement rates during the final period of operations.

The emplacement rate in Concept 3 (1.7 kW emplacement thermal power limit and 12PWR/21BWR waste package capacity) varies from 500 to 1,800 MTU/year during the first 170 years of operations and drops significantly after that (Fig. 3). Emplacing 99% of the inventory requires 197 years.

Two additional cases were considered for this concept. In the first case, 50% of the total inventory was emplaced in 12PWR/21BWR size packages and 50% was emplaced in smaller 4PWR/9BWR size packages. In the second case, 26% of the total inventory was emplaced in 12PWR/21BWR size packages and 74% was emplaced in 4PWR/9BWR size packages. The time required to emplace 99% of the total inventory was reduced by 51 years in the first case and by 79 years in the second case (Fig. 4). Even in the second case, a long repository operational time (118 years) was still required.

Note that in all simulations the total inventory is transported to the repository by 2102.

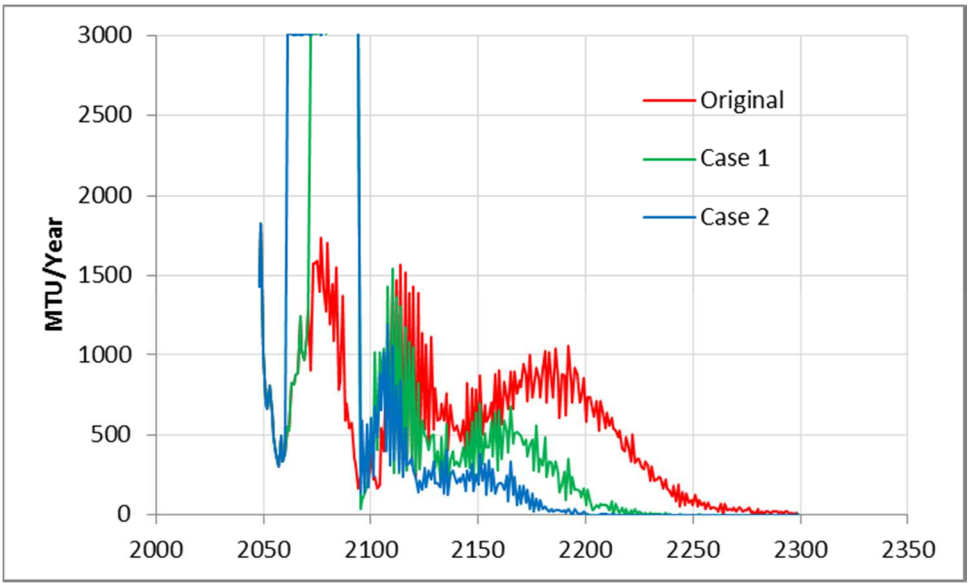
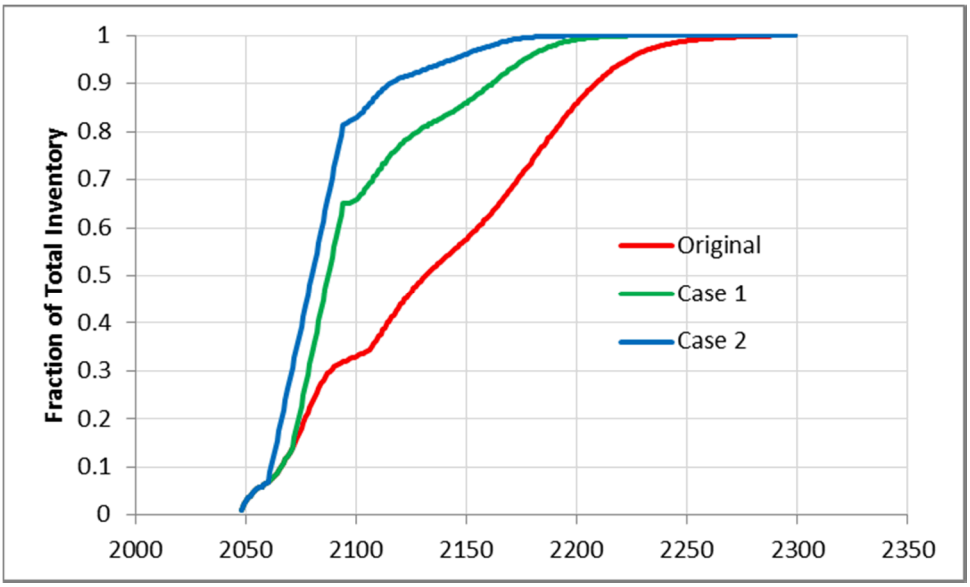


Fig. 3. Emplacement Rates for Disposal Concept 7 (DPCs, 11.5kW).



Case 1: 50% of inventory in 4PWR/9BWR. Case 2: 74% of inventory in 4PWR/9BWR

Fig. 4. Emplacement Rates for Disposal Concept 3 (12PWR/21BWR, 1.7kW).

DISPOSAL COST EXAMPLE

A few examples of the ROM disposal cost are provided below to demonstrate the differences due to geologic media and waste package capacities.

The ROM disposal cost ($Cost_{disp}$) was estimated as:

$$Cost_{disp} = CB_{media} + N_{WP} \cdot CWP_{media} \ , \qquad \text{(Eq.1)}$$

where CB_{media} ($M) is the base disposal cost specific to a geologic media, N_{WP} is the number of waste packages, and CWP_{media} ($M) is geologic media specific disposal cost per waste package.

Example 1: Same Waste Package Size (4PWR/9BWR) and Different Media

The base disposal cost for crystalline and argillaceous media was assumed to be 7,500 $M. The number of waste packages generated in Concept 1 (crystalline, enclosed) and Concept 2 (argillaceous, enclosed) is the same and equal to 81,885. Both concepts assume the emplacement thermal power limit of 1.7 kW and waste package capacity of 4PWR/9BWR. The disposal cost per waste package was assumed to be 0.885 $M for crystalline and 1.025 $M for argillaceous media. Applying Eq. 1 result in the disposal cost of 80$B for crystalline and 91$B for argillaceous media.

Example 2: Different Waste Package Size and Same Media (Hard Rock)

This example compares two unsaturated hard rock open mode concepts – Concept

9 and Concept 10. These concepts differ only by the waste package capacity, which is 21PWR/44BWR (Concept 9) and DPCs (Concept 10). Both concepts assume the emplacement thermal power limit of 18 kW. The number of waste packages is 16,068 in Concept 9 and 11,146 in concept 10. The base disposal cost for hard rock media was assumed to be 8,000 $M. The disposal cost per waste package was assumed to be 2.46 $M. Applying Eq. 1 result in the disposal cost of 48$B for 21PWR/44BWR waste packages and 35$B for direct disposal of DPCs.

Four different cases are compared in Fig. 5. Example 1 provides the upper ROM disposal cost estimate and Example 2 provides the lower end of ROM disposal cost estimate.

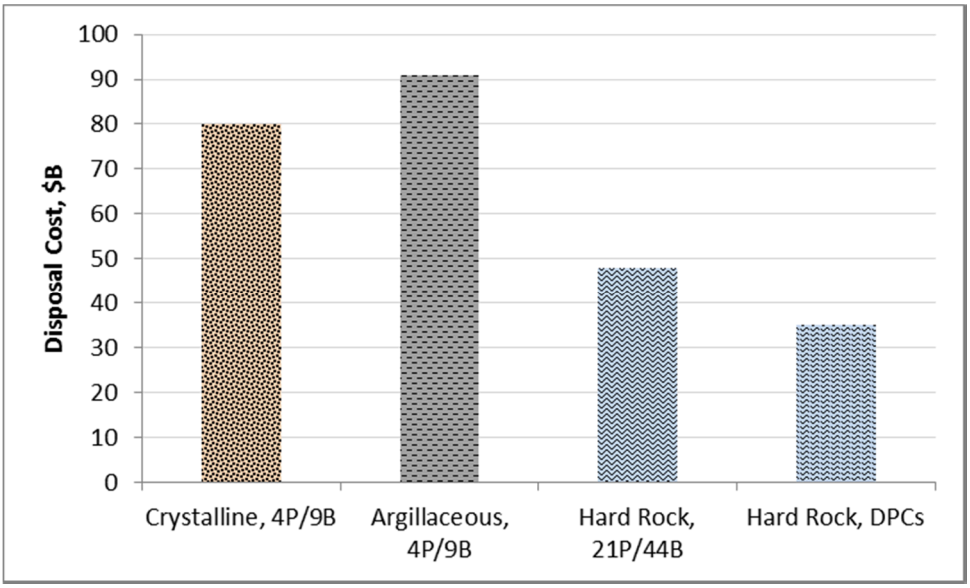


Fig. 5. ROM Disposal Cost for Different Media and Waste Package Capacities.

CONCLUSIONS

The summary of enveloping emplacement rates and duration of operation for 16 Disposal Concepts is presented in Table II.

The logistic simulation demonstrated that all the disposal concepts, except the one with the emplacement power limit of 1.7 kW and the waste package capacity of 12PWR/21BWR, are very similar with regard to the emplacement rates and duration of operations. The emplacement rate goal of 3,000 MTU per year can be maintained (or nearly so) from 2048 until 2092. Most of the inventory (99%) can be emplaced during the 45 to 54 years of repository operations. The remaining 1% of the inventory (1,400 MTU) requires some additional emplacement time or smaller waste packages.

TABLE II. Summary of Enveloping Emplacement Rates and Duration of Operation for 16 Disposal Concepts.

Concept		Waste Package Capacity (PWR/BWR)	140,000 MTU Repository	
			Emplacement Rate (MTU/year)	Duration of Operation (yr)
1	**Crystalline (enclosed)**	4/9	3,000	46
2	**Argillaceous (enclosed)**	4/9	3,000	46
3		12/21	1,700	~200 [A]
4	**Salt (enclosed)**	4/9	3,000	46
5		12/21	3,000	46
6		21/44	3,000	46
7		DPC	3,000	54
8	**Hard rock unsaturated (open)**	12/21	3,000	46
9		21/44	3,000	46
10		DPC	3,000	54
11	**Hard rock saturated (open)**	12/21	3,000	46
12		21/44	3,000	46
13		DPC	3,000	54
14	**Argillaceous (open)**	12/21	3,000	46
15		21/44	3,000	46
16		DPC	3,000	54

Note: [A] Shorter durations can be achieved by substituting smaller 4PWR/9BWR packages as indicated in Figure 4.

The emplacement rate in the disposal concept with the emplacement power limit of 1.7 kW and the waste package capacity of 12PWR/21BWR varies from 500 to 1,800 MTU per year during the first 170 years of operations and drops significantly after that. Emplacing 99% of the inventory requires 197 years. The duration of operations can be noticeably reduced if 50% or more of SNF inventory is emplaced in 4PWR/9BWR waste packages.

The disposal concepts with the same number of waste packages can have different total disposal costs. This is mainly due to the difference in the disposal cost per package, which is geologic media specific. For example, the ROM disposal cost in the crystalline media is 80$B compared to 91$B in the argillaceous media.

The disposal concepts related to the same geologic media with the same emplacement thermal power limit can have different total disposal costs. This is mainly due to the different number of waste packages. For example, the ROM disposal cost in hard rocks is 48$B if all the waste packages are 21PWR/44BWR compared to 35$B in the case of direct disposal of DPCs.

REFERENCES

1. ANDRA (National Agency for Radioactive Waste Management), *Dossier 2005 Argile – Architecture and Management of a Geological Disposal System.* ANDRA, France (2005).

2. NAGRA (Swiss National Cooperative for the Disposal of Radioactive Wastes), *Project Opalinus Clay Safety Report,* NAGRA Technical Report 02-05, Switzerland (2002).
3. NAGRA (Swiss National Cooperative for the Disposal of Radioactive Wastes), *Canister Options for the Disposal of Spent Fuel,* NAGRA Technical Report NTB 02-11, Switzerland (2003).
4. SKB (Swedish Nuclear Fuel and Waste Management Co.), *Long-Term Safety for the Final Repository for Spent Nuclear Fuel at Forsmark: Main Report of the SR-Site Project, Volume I,* Technical Report TR-11-01, Sweden (2011).
5. W.M. Nutt, E. Morris, F. Puig, E. Kalinina and S. Gillespie, *Transportation Storage Logistics Model – CALVIN (TSL-CALVIN),* FCRD-NFST-2012-000424, U.S. Department of Energy, Nuclear Fuel Storage and Transportation Project (2012).

ACKNOWLEDGMENTS

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.