# *PROCESSING HIGH-LEVEL WASTE IN THE US – A MATHEMATICAL MODEL*

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## Overview

The greatest problem the United States are facing regarding the storage of radioactive waste is the missing of a geological disposal site for high-level radioactive waste (HLW). The only existing permanent storage facility is the Waste Isolation Pilot Plant (WIPP) for defense waste in New Mexico. However, this repository only allows for low- and medium-level waste to be stored. Alone the change of current federal law including the WIPP Land Withdrawal Act would include WIPP in the short list of possible storage facilities. A real option for a repository is Yucca Mountain in Nevada as the necessary research has already been conducted and the geological repository is completed, being able to store up to 70,000 metric tons of waste.

This paper models the processing of HLW in the United States, as the U.S. has more nuclear plants than any other country in the world. Since the mid-1980s plans exist to move all the high-level radioactive waste to Yucca Mountain. Since handling radioactive material poses extreme risks, the costs associated with these tasks are enormous. We developed a model that evaluates the economic challenges for processing, transporting and storing HLW from all nuclear reactors in the US to the final repository in Yucca Mountain at the least possible costs.

## Methods

The model is one of transportation which includes a network consisting of all reactors in the U.S. as well as potential final repositories and potential locations for intermediate storages. It allows the building of a total of nine intermediate repositories strategically located around the whole country, so that the HLW does not have to be directly transported to the destination all at once. Furthermore, our goal is to achieve an economically optimal, achievable and sustainable plan of transportation and storage for HLW produced in all nuclear plants in the U.S.

The mathematical model is a mixed-integer problem consisting of linear constraints for balance and capacity limitations and the binary decision of building intermediate storages. The objective is the minimization of the overall cost consisting of storage costs, transportation costs, construction costs for building new storage facilities and processing costs. A total of five scenarios are implemented and discussed. Some consider solely the opening of Yucca Mountain as a final repository, whereas others also consider the extension of WIPP as a repository for HLW as well as evaluate reprocessing as an option to reduce the overall waste. The transportation follows the routes approved by the NRC and includes transport by train as well as by truck. The time frame of the model is the next 40 years but can be extended for a longer-term perspective. In addition, processing costs caused by the decay of transportation and storage casks for HLW are taken into account. The model differentiates between different types of waste: the main type is Spent Nuclear Fuel (SNF), here the amount produced until today as well as future production of SNF are considered. Furthermore, waste from decommissioning reactors and waste that has been reprocessed and vitrified are included in the model.

## Results

The overall costs for scenario 1 – only Yucca Mountain − estimated by our model amount up to about $ 3.154 billion. This is a relatively small sum compared to the costs occuring inside the reactors and the construction costs for a geological disposal facility. This leads to the conclusion that the costs of transportation of HLW are not the most decisive ones. Transportation costs seem to be less decisive than storage and technology costs (Figure 1). The interim storage capital costs make up almost half of the overall costs. The overall costs per year have a slight peak at the opening date of a final repository but are much lower afterwards (Figure 2).

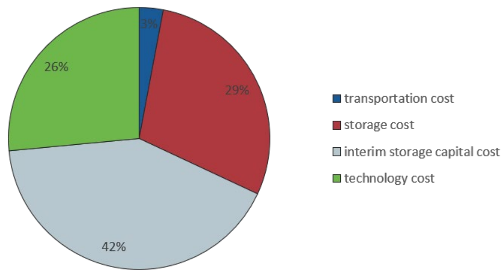


**Figure 1: Overall cost composition**

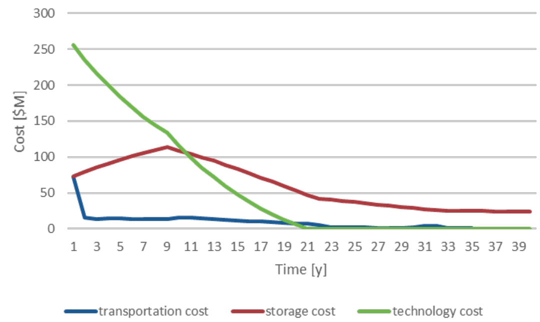


**Figure 2: Cost over time**

Vitrification of HLW seems difficult since it is not performed in the model due to the high costs for this process. But looking at other scenarios, that are not discussed in this paper, vitrification might become relevant as it is the only option of reducing the volume of HLW and thereby also reducing long term storage costs, if no final storage – with a large-enough capacity − is found.

Concerning the intermediate storage, it seems that the construction of three intermediate storage facilities would be necessary to provide storage capacity and reduce storage costs until the opening of final repositories. Locations should be strategically chosen either close to the reactors or close to a final repository under construction. In order to be cost efficient, a larger capacity in intermediate storage (at least 40,000 MTU) than the one the Department of Energy has planned to provide by 2025 would be needed.

## Conclusion

When comparing the results of the scenarios, the cost difference shows that any delay in finding and operating a final repository increases the overall waste disposal costs by at least 15-25% for any ten years of dealy. The construction of intermediate repositories will reduce the costs and improve the disposal process. Reprocessing is not cost efficient and not likely to be an option for the next decades. But when keeping the overall goal of having all HLW in a final repository in mind, the capacity of Yucca Mountain is not sufficient and another option, like a second repository or reprocessing to reduce the amount of HLW, will be needed.

Due to the lack of public information it is very hard to give accurate numbers on the real costs of the disposal process. Many assumptions had to be made to develop this model. We consider this one of the major issues regarding the quality of the results. Especially since most of the costs are estimated and their impact is critical for the result.

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