Benefits of Siting a Borehole Repository on Non-Operating Nuclear Facility - A Summary

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ABSTRACT

This paper is a summary of a longer paper accepted for International High Level Radioactive Waste Management (IHLRWM). This paper provides a creative solution for the two issues in the U.S. nuclear power : retiring reactors and overflowing spent nuclear fuel (SNF). The benefits of siting a borehole repository at a shutdown power plant is quantified with plausible metrics in the perspective of various stakeholders. The proposal demonstrates that such an integrated facility will have less cost, time and will be more plausible since it makes economic use of the shutdown power plant by utilizing its fuel handling facilities and local talent and infrastructure.

INTRODUCTION

This work evaluates the benefits of turning a shutdown reactor, a liability, to a borehole repository site, a much-needed facility. This work evaluates a strategy to do so that the remaining facilities are leveraged to cut costs and time for the repository, which makes the repository construction and operation more economical and politically feasible.

The expected benefits of this proposed integrated siting strategy include reduced radioactive waste transportation burden, increased likelihood of consent from the local community, and improved expediency achieved through leveraging existing infrastructure and skill.

The proposed case is compared to the case of Yucca Mountain, in six quantitative measures, in the perspective of four stakeholders.

Motivation

This work suggests borehole-design repositories for such integrated facility due it the design's modularity, wide geological suitability, and footprint efficiency. Borehole repositories need crystalline basement rocks at $2,000-5,000m$ deep, which is relatively common in the continental U.S [1]. Also, the area required for a borehole repository is only $30km^2$ for the capacity of Yucca Mountain [2].

The pre-existing local talent and infrastructure, is a major benefit to the proposed design. Compared to Yucca Mountain, where little infrastructure existed, a shutdown power plant is more likely to have usable infrastructure left, which can be utilized to save cost and time.

Lastly, the proposed design allows for more consent-based siting, since communities with nuclear facilities are more likely to be more receptive to the benefits of hosting a repository (i.e. jobs and taxes).

The purpose of this paper is to attempt to quantify the benefits, and compare them to the case of Yucca Mountain through a case study.

CASE DEFINITIONS

The paper focuses on the benefits that arise from the strategic siting of a repository on a non-operating nuclear facility, and not the benefits that arise from the repository design. The borehole design follows the Sandia Report Reference Design and Operations for Deep Borehole Radioactive Waste [3]. Selection of an alternative borehole concept could impact the details of the repacking needs and facility design, but will not significantly impact the siting comparison in this paper.

Case I: Reference Case

The reference case, upon which the proposed case seeks to improve, is to build a standalone 70,000 metric ton of heavy metal (MTHM) mined repository at the Yucca Mountain site.

The reference case is presented in order to demonstrate the cost savings and efficiencies that arise from the proposed case. The base case mimics the Yucca Mountain Project. Costs include new licensing and processing facility for repacking the spent fuel assemblies.

Case II: Shut Down Plant Case

The imminent shutdown of the Clinton Nuclear Power Station has recently been averted by an act of the state legislature. In this sense, Clinton is representative of a class of at-risk nuclear reactors in the Midwest and eastern United States. A borehole repository sited at the Clinton Nuclear Power station site is therefore hypothetically considered here to represent integrated repository siting at a reactor facility faced with potential shutdown.

The Clinton Nuclear Power Station is owned by the Exelon Corporation. It has a licensed land area of approximately $58km^2$ and a $20km^2$ cooling heat sink, the Clinton Lake. Of the licensed land area, only $0.6km^2$ is used for the facility. [4]. This leaves enough room left for a 70,000 MTHM borehole repository without additional land purchase from the public.

METHODOLOGY

This work will evaluate **2 scenarios** for repository siting according to **6 metrics** of performance considered from the perspective of **4 stakeholders.**

This work will evaluate the potential impacts of each siting strategy according to the following 6 quantitative measures:

- Transportation Burden [$MTHM \cdot km$]: A site is preferred by most stakeholders if it can minimize the distance SNF must travel.

- Workforce Utilization [−]: A repository site is preferred by many stakeholders if it utilizes an already situated skilled local workforce.
- Expediency [y]: Many stakeholders will benefit if the removal of dry casks from current storage pads is expedited.
- Consent Basis [$\frac{nuclearMW}{\text{capita}}$]: If the community beneifts from nuclear energy, they are more likely to be consenting to site a repository. If there is a basis for a consent-based siting process to succeed, many stakeholders benefit.
- Site Access [−]: Rail access to the site is essential for beginning operations.
- Site Appropriateness [−]: A site must be geologically appropriate and of sufficient area.

Finally, recognizing that these measures are valued differently by each, we consider possible weighting factors that may capture the perspectives of 4 key stakeholder groups:

- the federal government,
- the state government,
- the local government / community,
- and the owner of the non-operating plant.

EVALUATION METRICS

This paper introduces six metrics of siting performance. These metrics and their definitions draw upon previous [6, 5] as well as original work. In the following sections, the metrics are defined in more detail, and normalized so that in the final section, they are applied to comparatively evaluate each case.

The normalization of the metrics are done to a scale of 0 to 1 using the equation below, where 0 is the worst possible value, and 1 the best. Metrics like transportation burden, expediency, and consent basis, are normalized in such a matter. Metrics without units are booleans, where values only exist in values of 0 or 1. For example, a 0 value for site access means that there is no existing site access infrastructure.

$$\text{NV} = \frac{x - \text{W}}{\text{B} - \text{W}} \tag{1}$$
$$NV = \text{normalized value for the metric} \tag{2}$$
$$x = \text{considered case value for the metric} \tag{3}$$
$$B = \text{best case value for the metric} \tag{4}$$
$$W = \text{worst case value for the metric} \tag{5}$$
$$\tag{6}$$

Transportation Burden

A metric for representing the distance a mass of spent fuel must be transported, the transport burden, is introduced. This transportation burden is the product of the SNF mass and the distance it has to travel from its current storage location to the proposed repository. This results in a metric in units of $MTHM \cdot km$.

To arrive at the transportation burden for each case, a distance analysis was completed using the Haversine formula [7]. First, the coordinates of each power plant were obtained by scraping public data [8]. The distance between each storage site (i.e. reactors and Independent Spent Fuel Storage Installation (ISFSI)) was then calculated by using the Haversine formula on the geographical coordinates of the receiving and sending sites (1 and 2).

This analysis used GC-859 spent fuel inventory data available from U.S. Energy Information Administration (EIA) through private communication [9] as well as Centralized Used Fuel Resource for Information Exchange (CURIE), a web interface to the Oak Ridge National Laboratory (ORNL) universal database[10]. From the list of 74 sites, several candidates which minimize $B[MTHM \cdot km]$, spent fuel transportation burden, are listed in Table 1.

TABLE I. Reactors with relatively small spent fuel transportation burden [$MTHM \cdot km$].

Reactor	State	$MTHM * km$	License Area [km^2]
Clinton	Illinois	**77,352,339**	**57.87**
Dresden	Illinois	**77,663,969**	3.856
Peach Bottom	Pennsylvania	85,563,135	2.509
Indian Point	New York	84,097,374	.967
Yucca Mountain	Nevada	209,575,157	N/A

The Clinton Power Plant was chosen as the site for the proposed case due to its small $MTHM \cdot km$ value and substantially large license area[4].

TABLE II. Transportation Burden for Each Case

Case	Transportation Burden [$MTHM \cdot km$]	NV
Case I	209,575,157	0
Case II	77,352,339	1

Site Appropriateness

To host a borehole repository, the site must satisfy geologic requirements. Figure 1 is a map indicating the geological fitness of various regions of the United States. The proposed site at Clinton sits above a crystalline basement which lies at an appropriate depth.

TABLE III. Site Appropriateness for Each Case

Case	Site Appropriateness
Case I	1
Case II	1

Workforce Utilization

The Clinton Power Station has approximately 700 employees living in nearby counties with an additional several hundred contractors during fuel outages[13]. The existing skilled workers and local talent for maintenance, transport and catering services can be utilized without bringing a whole new group of workers to the area [14]. Also, the shutdown of Clinton Power

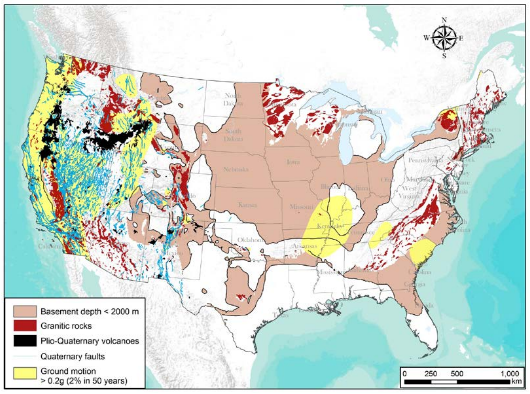

Fig. 1. From [12], a map of areas in the US with crystalline basement rock at less than 2000 meters depth. Tectonic activity impacting siting considerations are also mapped: Quaternary faulting, volcanism, and seismic hazard (yellow shading = 2% probability of exceeding 0.2 g of ground acceleration in 50 years).

Plant would cause a dramatic loss of jobs in the community.

The proposed case has a larger advantage over the base case in the sense that there are already existing facility in regards to spent fuel handling and worker lodging and catering services. It is assumed, for the sake of argument, half of the construction cost of the repacking facility in the base case is used to expand the existing facility in the proposed case.

TABLE IV. Workforce Utilization for Each Case

Case	Workforce Utilization
Case I	0
Case II	1

Consent Basis

International SNF siting experiences have shown that a consent-based approach to siting a repository is crucial to success [11, 17, 18, 6]. Furthermore, the Swedish precedent [19] shows that municipalities near nuclear facilities are more likely to volunteer to site a repository in their community.

Because populations local to operating reactor sites are more likely to be favorable toward nuclear power, and the proposed integrated siting is in an already-nuclear community by design, this siting strategy inherently maximizes the local consent basis.

The source of this favorable attitude varies by site. The local community is the beneficiary of various economic benefits including job creation and the substantial property taxes paid by the utility toward regional governmental budgets. In the case of the Clinton Power Plant, Exelon pays $15 million in property taxes each year, which amounts to about $923 per resident in the host Dewitt county [20]. The plant also provides a total payroll of more than $50 million to its workers. The eventual shutdown of the plant would have caused a dramatic loss of the economic inflow. It is also speculated that 13,300 jobs would be lost in Illinois after five years of plant shutdown [21].

A similar phenomenon might be expected at the state level as well, because Illinois generates more nuclear energy than any other U.S. state with a net capacity of 11,441 megawatts in 2010 [22]. Nevada, on the other hand, hosts zero nuclear power plants. Thus, it can only be natural for Nevada to consider a national repository as an unjust burden, despite economic benefits.

The consent basis, driven by proximity to an operating nuclear plant and corresponding greater likelihood to be favorable toward hosting an SNF repository, should be quantifiable by a measure of the benefit experienced by the community. For simplicity, we quantify the proximity to nuclear energy at the state level based on power consumed. The corresponding state and regional metrics (expressed in MW of nuclear power per capita) are listed in Table V. This analysis uses nuclear power generation capacity and population data from the U.S. EIA [22] and the U.S. Census [**?**].

TABLE V. Nuclear MW Per Capita (NMWPC) values for different states

State	Net Nuclear Capacity (MW)	Census Population	NMWPC (10^{-3})
South Carolina	6,486	4,625,401	1.4
Alabama	5,043	4,780,127	1.05
Vermont	620	625,745	.99
Illinois	11,441	12,831,549	.89
Nevada	0	2,705,000	0
Average Nuclear States	101,167	265,386,569	.38
Average National	101,167	309,300,000	.33

The state of Illinois has the highest generating capacity, and is fifth in the NMWPC value, while Nevada has zero generating capacity with zero MW per capita value. Illinois' NMWPC value is also well above the national average. Judging from the table, it is no surprise that the state of Nevada rejected the idea of having a national spent fuel repository on its land. On the other hand, Illinois is more familiar with nuclear and also somewhat reliant on nuclear, which can lead to a consent-based process in a state-level.

TABLE VI. NMWPC values for Each Case

Case	NMWPC	NV
Case I	0	0
Case II	.89	.635

Site Access

Site access necessary to transport radioactive material to the repository site poses one of the greatest logistical challenges in siting a repository.

In the case of Yucca Mountain, the opposition from the state of Nevada to the proposed Caliente rail corridor blocked construction of the rail line and indefinitely postponed acceptance of SNF at Yucca Mountain [23].

Operating reactors, conversely, are much more likely to be located along rail lines. In the case of the Clinton nuclear power plant, the Canadian National rail line [5] has a station in Clinton and dedicated tracks leading into the reactor facility, as shown in Figure 2. An already existing railway can avoid costs and delays related to building a new infrastructure.

The proposed site's proximity to other power plants means that the transport routes pass through fewer states and communities, which lessens the potential for conflict.

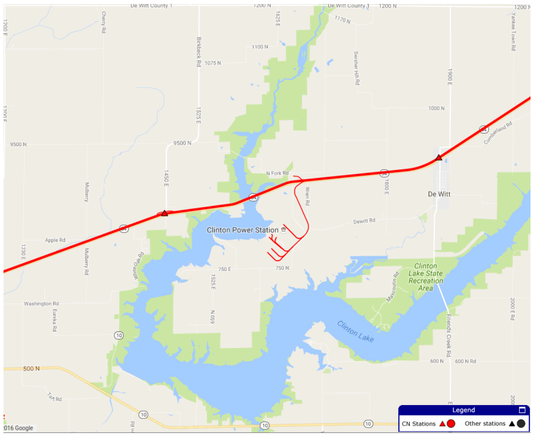

Fig. 2. From [24], a map of Clinton Power Station in Clinton,IL with the Canadian National rail passing through.

TABLE VII. Site Access for Each Case

Case	Site Access
Case I	0
Case II	1

Expediency

Leveraging existing infrastructure at an integrated site will allow for expedited acceptance of SNF from temporary dry cask storage sites nationwide.

Dry casks are the result of the perpetual delay of a repository construction. The proposed case would allow reactor sites to empty their spent fuel pools, which would no longer necessitate dry storage campaigns. For example, Maine Yankee's ISFSI cost was $149.3 million in 2001 dollars, with an annual operating fee of $10 million per year [26].

The proposed case, once completed, will allow faster acceptance of SNF and, accordingly, resumed collection of the Nuclear Waste Fund (NWF), which will fund the repository operation and maintenance.

The proposed case, being a once-operating nuclear power plant, has the facility to repack the spent fuel assemblies into a disposal cask. Its dry cask infrastructure is currently in use. However, this facility needs to be upgraded to increase its throughput, and should be preferably automatic, to minimize worker exposure. The transported spent fuel assemblies are repacked and inspected at the upgraded facility, and is sent to the emplacement tubes for final disposal. Not having to build an entirely new above-ground facility should greatly ease the consent-based process, for it seems like there would be minimal impact.

A metric for expediency is then proposed which is inversely proportionate to the number of years until the federal government takes possession of the spent fuel. Estimating the likely timelines for each case is a challenge beyond the scope of this work. However, a bounding estimate can be derived from the time saved from use of existing infrastructure at the integrated facility. Avoiding that handling facility delay will save at least 5 years and likely much more on the timeline of Case II over that of Case I [27].

TABLE VIII. Expediency in Each Case

Case	Time Saved [y]	NV
Case I	0	0
Case II	5	1

RESULTS AND DISCUSSION

To model the impact of these measures on the incentives of each stakeholder, the list of stakeholders considered follows in Table IX alongside the weights indicating the magnitude of the importance of the incentive.

TABLE IX. Metrics and Weight for Each Stakeholder

Metric	Federal	State	Local	Utility
Transportation Burden	3	2	1	1
Site Appropriateness	3	2	1	1
Workforce Utilization	3	2	2	2
Consenting Locals	3	2	3	2
Site Access	3	2	1	1
Expediency	3	2	1	3
Case I total	3	2	1	1
Case II total	16.9	11.2	7.9	9.2

Results show that it is far more attractive for various stakeholders to site a repository at a non-operating nuclear power plant. Through strategical siting, all the parties involved can benefit.

Given the current circumstances, a repository is crucial for the survival of nuclear power. By siting one in a central location with sufficient licensed land, a repository with sizable capacity can be built cheaper, more efficiently, and in a consent-based manner with the local community.

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