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

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ABSTRACT

This work evaluates a potential solution for two pressing matters in the viability of nuclear energy: spent fuel disposal and power plants that no longer operate. The potential benefits of siting a borehole repository at a shut-down nuclear power plant facility are analyzed from the perspective of myriad stakeholders. This assessment indicates that integrated siting will make economic use of the shut-down power plant, take advantage of spent fuel handling infrastructure at those sites, minimize transportation costs of emptying the crowded spent fuel storage pools at nearby reactors, and will do so at sites more likely to have consenting communities.

INTRODUCTION

Faced with the challenge of nuclear spent fuel disposal siting, creative solutions are necessary. This work proposes and evaluates a strategy that leverages the remaining resources inherent in a shutdown nuclear reactor site toward a new purpose: a consolidated interim storage and spent fuel repository facility.

Domestic nuclear power plants are at risk of shut down in areas with surplus electricity capacity from coal and new natural gas. Kewaunee and Crystal River have already closed and numerous other plants are scheduled to shut down in the next few years [**?**]. Simultaneously, the Department of energy has begun to move forward with consent-based siting of a nuclear spent fuel repository [**?**]. The proposed solution in this work seeks to combine these efforts toward a more economic and politically feasible solution.

This work compares a base case which is to site a borehole-type repository in the Yucca Mountain region, to a base case, which is to site a borehole-type repository next to a shutdown nuclear power plant. The main expected benefits arising from the proposed case is transportation burden of radioactive waste, more consent-based siting with the local community, and modularity of the repository.

Each incentive criteria in the comparison is given a numerical value, which is weighted to its importance to various stakeholders.

Motivation

The proposed integrated siting strategy takes advantage of three technical benefits of borehole repository designs: modularity, broad geological suitability, and footprint efficiency. Modularity enables regional repositories to scale in size according to the local spent fuel burden. Additionally, the necessary geological characteristics required for borehole disposal, crystalline basement rocks at $2,000m - 5,000m$ deep, are relatively common in stable continental regions [**?**]. Finally, the surface footprint requirements of a borehole repository are comparable to the available footprint of a nuclear power reactor site, with only $30km^2$ required for the total spent nuclear fuel (SNF) amount proposed for Yucca Mountain [**?**].

Integrated siting also has potential economic benefits. One significant cost inherent to borehole repository concepts is the repacking of spent fuel assemblies into smaller-diameter waste canisters. However, siting a repository at a non-operating power plant facility, especially one with a dry-cask storage site, will take advantage of already existing infrastructure and local human talent for spent fuel handling and packaging. Many candidate non-operating reactor sites, such as those mapped in Figure 1 may be appropriate for integrated siting if they are located above crystalline basement formations and include dry cask packaging facilities.

Preliminary work [**?**] indicates integrated siting is appealing to many stakeholder groups. For example, a consent-based approval process may be feasible because communities local to power plants may be uniquely receptive to the incentives of hosting a repository.

METHODOLOGY

This work will evaluate the potential impacts of integrated siting from the perspective of 5 stakeholders:

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

Preliminary work [**?**] suggests that integrated siting will reduce costs, construction, time (both for construction and licensing), transportation distances, and resistence from the local community. The present work will compare the proposal along these axes to a base case: a standalone borehole repository at a similar location to that of Yucca Mountain. Quantification of those stakeholder benefits will be undertaken for two different regions of the US in addition to the base case.

Unique parameters are quantified using simple calculations from easily accessible data. The goal of this paper is to quantify different metrics in numbers in order to clarify siting methodology.

CASE DEFINITION AND SPECIFICATIONS

This paper sets the proposed case to building a 70,000 metric ton of heavy metal (MTHM) capacity borehole repository

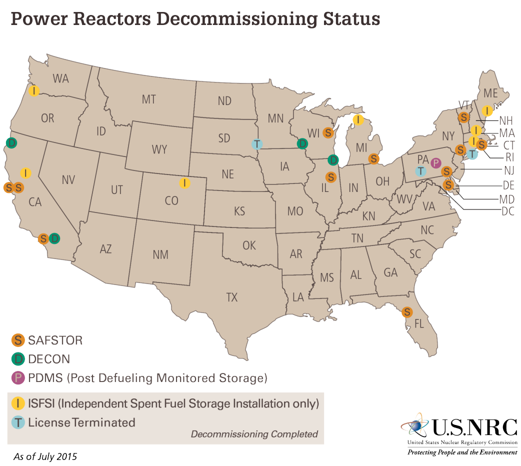

Fig. 1. Non-operating facilities status [?].

at the Clinton Power Plant in Illinois. The base case is to build a standalone borehole repository at a location similar to that of Yucca Mountain with the same capacity. The borehole design follows the Sandia Report Reference Design and Operations for Deep Borehole Radioactive Waste [?]. However,the difference in design of borehole will not contribute directly to the analysis for the design is the same for both case. The design will affect the necessary repacking facility to repack the individual rods into a emplacement canister.

Proposed Case Methodology and Definition

In order to minimize transport cost, a central location is preferred. A metric for representing the spent fuel transport burden, mass distance, is the product of the waste volume and the distance it has to travel. This results in a metric in units of $MTHM \cdot km$.

This distance analysis was completed using the Haversine formula [?]. First, the coordinates of each power plant were obtained by scraping public data [?]. The distance between each storage site (i.e. reactors and Independent Spent Fuel Storage Installation (ISFSI)) was then calculated by using the Havershine formula on the geographical coordinates of both sites.

$$\Phi_1, \Phi_2 = \text{latitude, radians} \tag{1}$$

$$\lambda_1, \lambda_2 = \text{longitude, radians} \tag{2}$$

$$\Delta\lambda = |\lambda_1 - \lambda_2| \tag{3}$$

$$\Delta\Phi = |\Phi_1 - \Phi_2| \tag{4}$$

$$a = \sin^2(\Delta\Phi) + \cos(\Phi_1)\cos(\Phi_2)\sin^2\left(\frac{\Delta\lambda}{2}\right) \tag{5}$$

$$c = 2arctan2(\sqrt{a}, \sqrt{1-a}) \tag{6}$$

$$d = (6,371km)c \tag{7}$$

Finally, this distance value is multiplied by the MTHM that needs to be transported.

$$b_1 = m_1 d \tag{8}$$

$$B = \sum_i^N b_i \tag{9}$$

where

$$b_1 = \text{spent fuel transport burden from facility 1} \tag{10}$$

$$B = \text{total spent fuel transport burden} \tag{11}$$

$$N = \text{total number of facilities with spent fuel on site.} \tag{12}$$

The spent fuel inventory data is from the GC-859 survey data from the U.S. Energy Information Administration (EIA) [?] and the Centralized Used Fuel Resource for Information Exchange (CURIE) website. From the list of 74 reactors, several candidates which minimize $B[MTHM \cdot km]$, spent fuel transportation burden, are listed below:

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**
Peach Bottom	Pennsylvania	85,563,135	2.509
Indian Point	New York	84,097,374	.967
Dresden	Illinois	**77,663,969**	3.856

With recent events, another scenario can be proposed, with the possible revival and actualization of the Yucca Mountain project, a dual-repository scenario can be proposed, with both the Yucca Mountain repository and the near-Clinton borehole repository operational. The fuel spent storage sites were divided depending on their longitude, where spent fuel west of the 92 west meridian is considered west, which will send its waste to Yucca Mountain. Conversely, spent fuel east of the 92 west meridian is considered east, which will send its waste to the proposed Clinton power plant. The 92 west meridian is chosen because it is the meridian just west of Illinois state borders, so that no Illinois power plants have to transport their spent fuel to Yucca Mountain.

However, this way of partitioning gives Yucca Mountain approximately 14,000 MTHM, which is greatly under its proposed capacity of 70,000 MTHM. On the other hand, the Clinton repository would receive 61,777 MTHM. The $MTHM \cdot km$ value is 53,945,200 for Yucca Mountain, and 17,940,959 for the Clinton repository. This adds up to a sum of 71,886,160 $MTHM \cdot km$, which is about 7% less than that of Clinton repository alone. This does not provide a comparable advantage. Other reactor sites were tested in the transportation burden analysis but also failed to provide a substantial advantage. Also, the selection of different reactors were limited by the geological constraints, which is shown in figure 2.

If the power total MTHM value were to be equal, a line is drawn at the 84 west meridian, which yields $39,942 MTHM$ for the east repository, and $36,649 MTHM$ for the Yucca Mountain repository. One of the original candidates, the Peach Bottom reactor in Pennsylvania is then chosen for its central location in the east area. However, this analysis yields a $MTHM \cdot km$

value of $92,575,081 MTHM \cdot km$, which is substantially larger than that of having one repository in Clinton. Also, the Peach Bottom reactor site has little licensed land, which will require additional land purchase for the repository.

The Clinton Power Plant is chosen as the site for the proposed case due to its low $MTHM \cdot km$ value and substantially large license area[?]. Considering that only $30 km^2$ is required for all the total SNF amount, the licensed area at Clinton power plant allows more than enough space to site a borehole repository, which avoids possible conflicts with the community from purchasing and utilizing more land.

The proposed case requires a great amount of cooperation from the utility that owns the Clinton power plant, Exelon Corporation. Currently, Exelon has no incentive to cooperate, for they do not pay for storage of spent fuel, due to the 2004 settlement with the Department of Justice.Also, Exelon currently owes approximately a billion dollars to the Nuclear Waste Fund (NWF), (gaining interest at U.S. Treasury bond rate) when a repository is completed [?] Exelon has an incentive to cooperate, since it will earn profit throughout the construction and operation of the repository at its power plant, as well as to utilize the unused land mass in a lucrative manner. Also, Exelon would not have to pay for operation or construction, since it is the government's responsibility to dispose nuclear spent fuel [?].

The figure below demonstrates the geologic fitness of the proposed site, where a crystalline basement lies at a depth of less than 2,000 meters.

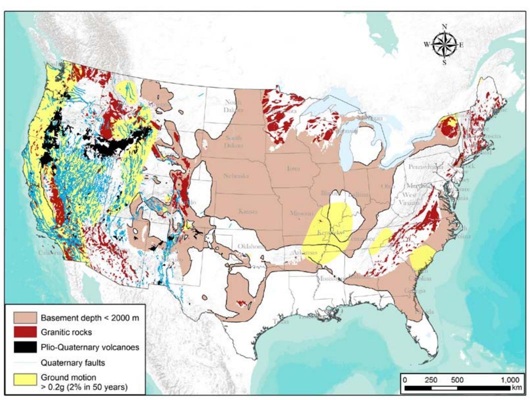

Fig. 2. From [?], a map of areas in the US with crystalline basement rock at less than 2000 meters depth. Tectonic activity impacting siting considerations are also mapped: Quaternary faulting, volcanism, and seismic hazard (yellow shading = 2% probability of exceeding 0.2 g in 50 years).

Also, from the Decatur Carbon Sequestration Project, there is ample data on the stratigraphy of the Decatur region, which is less than 50 miles south of the Clinton power plant.

Base Case Methodology and Definition

The base 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 but is a borehole-type repository. Costs include new licensing and processing

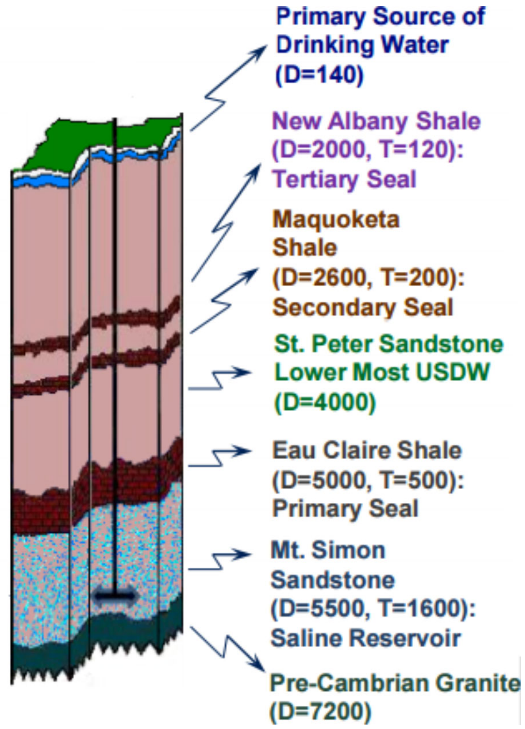

Fig. 3. Stratigraphy of the Decatur Region [?].

facility for repacking the spent fuel assemblies.

INCENTIVES TO VARIOUS STAKEHOLDERS

Prior to discussing the benefits of the proposed case over the base case, the list of stakeholders and their incentives are listed below, with a number indicating the magnitude of the importance of the incentive.

TABLE II. Incentive Criterion and Weight for Each Stakeholder

	Federal	State	Local	Utility
Job Creation		1	3	1
Consenting Locals	3	2	3	
Transport	2	1	2	
No Need for additional land purchase	3	2	3	
Cease of Dry Storage Campaigns	3			3
Net Cost	3			3
No New Above-Ground Facility Construction	3			3

Job Creation

Building a spent nuclear fuel repository is no easy task. It is a task that requires numerous experts and labourers. Also, operating and maintaining a nuclear power plant requires numerous experts and labourers. In case of the proposed case, the Clinton Power Station has approximately 700 employees living in nearby counties with an additional several hundred contractors during fuel outages[?]. 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 [?]. Also, the shutdown of Clinton Power Plant would cause a dramatic loss of jobs in the community.

The void created by the shutdown of the Clinton plant can be, though not completely, filled by the new construction of a borehole repository. The construction will prioritize local hires as an incentive to ease local opposition on repository siting. Employment during the operation of Yucca Mountain was estimated to range from 2,000 to 5,000 jobs, [?] which means that the borehole repository would at least require half of the workforce for the same capacity.

Additionally, an estimate by the Illinois State University on fracking the New Albany Shale in southern Illinois estimated that such a project can create 1,000-47,000 jobs [?]. Translating the workforce to central Illinois and the borehole project should create somewhere in the low and medium estimate, which is about 10,000 jobs.

Consenting Locals

It is proven, through many global nuclear waste repository projects, that a consent- base approach to siting a repository is crucial. For such a development to happen, an amiable local community is crucial. The proposed case provides various economic benefits to the local community including job creation, as mentioned above, and other benefits like property taxes. Clinton Power Plant pays $15 million in property taxes each year, which amounts to about $923 per resident in the host Dewitt county [?]. The plant also provides a total payroll of more than $50 million to its workers. The eventual shutdown of the plant would cause a dramatic loss of the economic inflow. It is also speculated that 13,300 jobs will be lost in Illinois after five years of plant shutdown [?].

In a state level, Illinois is the highest generator of nuclear energy, with a net capacity of 11,441 megawatts in 2010 [?]. This is in comparison to Nevada, where they had zero nuclear power plants. It can only be natural for Nevada to consider a national repository as an unjust burden, despite economical benefits. However, the state of Illinois, with its close connection with nuclear energy, has a higher sense of obligation to do something about the nuclear waste problem.

Since the economic loss from the shutdown of the plant can be mediated by the construction and operation of the repository, the proposed case is more likely to have a welcoming local community than the base case.

Also, the Swedish precedent shows that municipalities that has nuclear facilities are more likely to volunteer to site a repository in their community [?]. Since the proposed community is focused around a nuclear power plant, it is more likely for the siting procedure to be consent-based.

Transport

Transport of radioactive material is a difficult matter, and poses one of the greatest problems in siting a repository. For obvious reasons, the transport of spent fuel is preferred to be minimized, and the least intrusive. Also, the cost of transporting nuclear spent fuel is

The proposed case, according to the crude analysis,has the least amount of required transportation of spent fuel. Also, it is conveniently located near the Canadian National rail line [?]. An already existing rail way can save the cost of building a new infrastructure.

The proposed site's proximity to other power plants means

Fig. 4. From [?], a map of Clinton Power Station in Clinton,IL with the Canadian National rail passing through.

that the transport routes trespass less states and communities, which lessens conflict.

The capacity of the state to handle nuclear materials is also important. The state of Illinois established a Division of Nuclear Safety in its Illinois Emergency Mangament Agency (IEMA) which connects the state police and the Illinois Commerce Commission (ICC) to successfully transport 480 shipments of spent nuclear fuel since 1983 [?]. If a repository is built and operational, the already existing, experienced state organization will be able to handle the transportation logistics and security.

Conversely, the base case has a $km * MTHM$ value of $209,575,157 km * MTHM$, which is approximately 2.7 times more than that of the proposed case. Also, the transportation route to Yucca Mountain is identified to traverse 955 counties with about 177 million persons, which is about 56% of the US total [?]. The trespass is a sensitive topic to some states, and may demand reroutes that cause unexpected cost increases in transportation. Also, new railways would need to be constructed in order to ship the spent fuel inventories by rail.

No Need for Additional Land Purchase

The proposed case has a licensed land area of approximately $58km^2$ and $20km^2$ cooling heat sink, the Clinton Lake, with only $.6km^2$ being used for the facility. [?] This leaves enough room left for a 70,000 MTHM borehole repository without additional land purchase from the public.

However, the base case also does not require land purchase, for the land near Yucca Mountain is part of the Nevada Test Site.

The proposed case has a disadvantage in this aspect, because the government then has to pay Exelon for the land and the facilities. In theory, the government would purchase the entire property from Exelon, when Exelon shuts down the reactor. This would suggest a beneficial trade for both parties, since the government can purchase infrastructure and land simultaneously, and since Exelon can vastly save the cost of decommissioning by selling off the reactor site. The reactor core and power-generating component of the reactor site needs to be decommissioned, however. As a comparison, Maine Yankee, a PWR with a capacity of 860MWe, had a decommissioning cost of 635 million [?].

Also, Clinton Power Plant, being a single unit power plant, has a much higher employee-per-GW ratio of 631, compared to, for example, 344 employee-per-GW at the Braidwood Power Plant, also in Illinois. With its inherent lack in efficiency for operation and maintenance, it would be an incentive for Exelon to host a repository to generate extra revenue.

Cease of Dry Storage Campaigns

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 [**?**].

The proposed case, if completed, will allow resumed collection of the NWF, which will fund the repository operation and maintenance.

The base case has the same benefits.

Pre existing Talent and Infrastructure

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.

No New Above-Ground Facility Construction

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's minimal impact.

The utility has a very high incentive since it will save on its decommissioning fee. The construction of the repository next to the reactor site would substantially reduce the cost of decommissioning, and it would not have to expand its dry storage to empty out the pools. Exelon would be getting a profitable margin out of a used nuclear power plant, which would otherwise be a cost burden to handle.

The base case requires a new above-ground facility, which not only costs a great amount, but also will be considered problematic to the public's eye.

RESULTS AND DISCUSSION

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

ACKNOWLEDGMENTS

This material is based upon work supported by Program in Arms Control & Domestic and International Security (ACDIS). Preliminary work was conducted in collaboration with the Independent Student Research Group (ISRG) within the Department of Nuclear, Plasma, and Radiological Engineering (NPRE). The authors are accordingly grateful for guidance by Prof. Clifford Singer.